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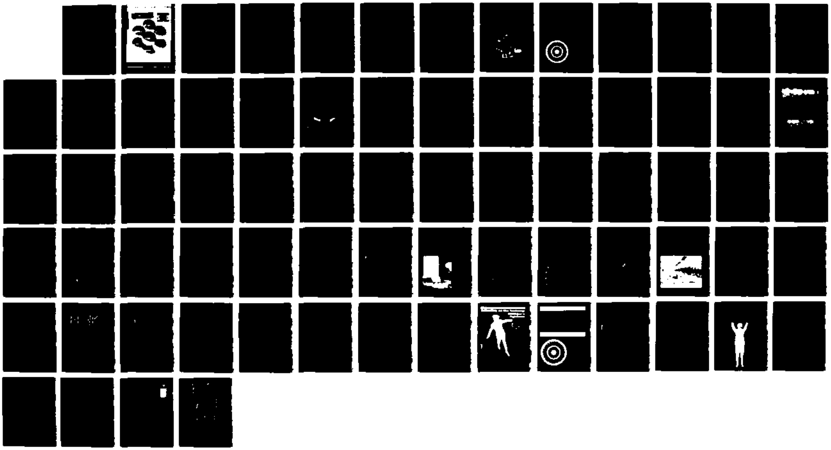

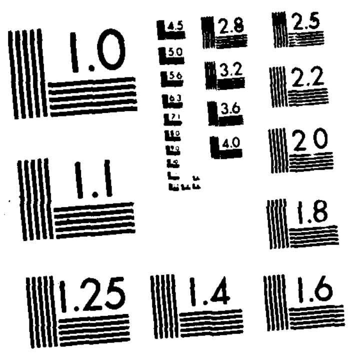

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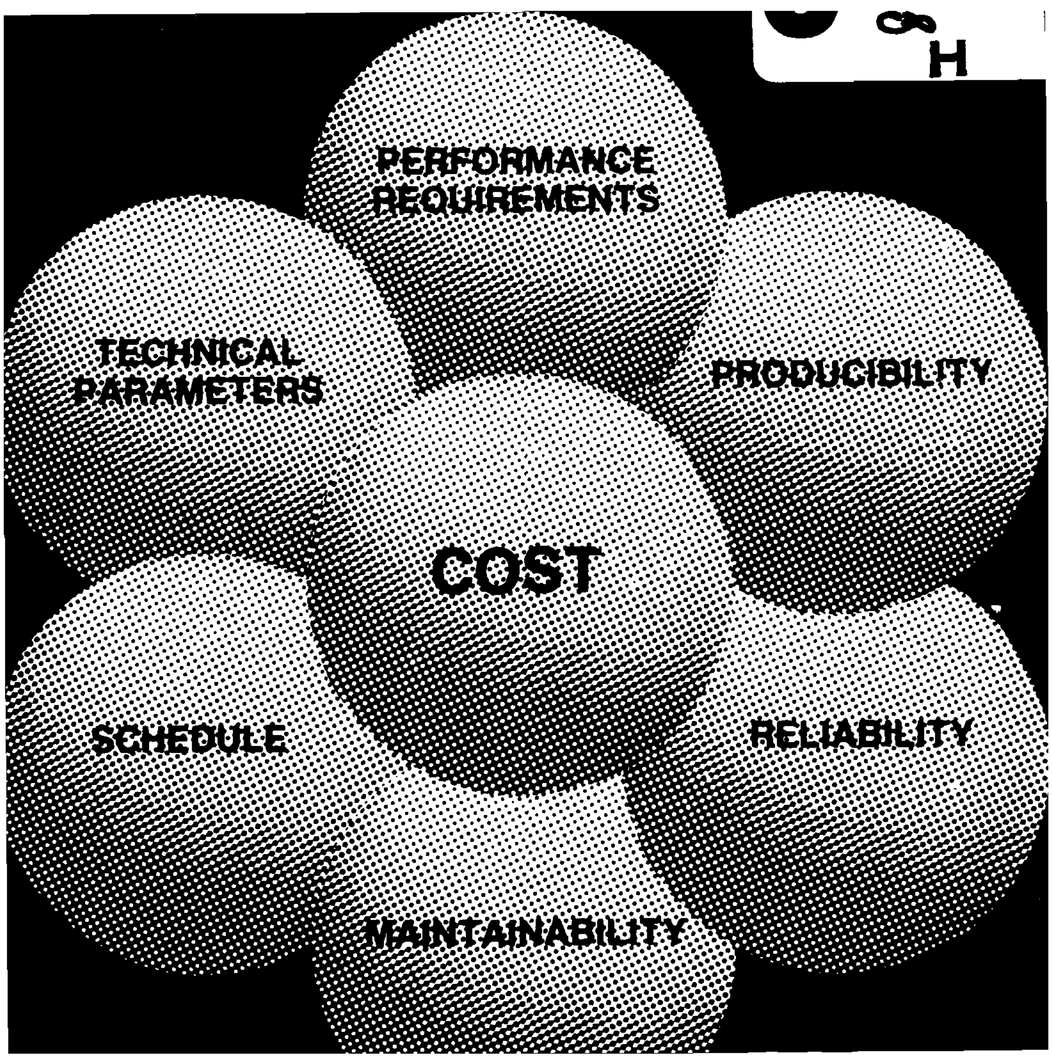
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In this monograph Professor Wilbur V. Arnold describes contemporary tools, talent, issues, and techniques applicable to designing defense products. The objectives are to provide insight for managers concerned with the design function and to provide designers with better understanding of the scope, tools, and issues involved. The material is based on publications by Professor Arnold (and as co-author) in the Defense Systems Management College Program Manager, and readings and charts developed for the college's Program Management Course by the author and faculty members of the Technical Management Department.

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DESIGNING DEFENSE SYSTEMS

WILBUR V. ARNOLD

FOREWORD

This monograph describes contemporary tools, talent, issues, and techniques applicable to designing defense products. The objectives are to provide insight for managers concerned with the design function and to provide designers with better understanding of the scope, tools, and issues involved.

First considered is designing for the life cycle of the product. This relates designing for performance to designing for quality, reliability and maintainability, production, special systems requirements (e.g., system safety, human engineering, electromagnetic compatibility, contamination and corrosion control, survivability/vulnerability, hardware/software integration, operation and support) and cost. These individual technical functional designs and the interrelationships of performance, fitness for use over the life of the equipment, scheduled deliveries and budget constraints are discussed. Then, managing the design process is discussed followed by the state-of-the-art in design tools, talent, and computer aids for the task.

The material is based on publications by the author (and as co-author) in the Defense Systems Management College *Program Manager*, and readings and charts developed for the college's Program Management Course by the author and faculty members of the Technical Management Department.

ACKNOWLEDGEMENTS

The material contained herein was accumulated from many sources. It is practical to give credit to current users of this classroom data but in most cases the original source is impractical to identify. We assume the continual exposure of this material in Defense Systems Management College (DSMC) lessons verifys its credibility and utility in government publications.

Drafts of this document which incorporates material from the DSMC Technical Management Department (TMD) file have been circulated through the department for comments. Assistance by the faculty is greatly appreciated. Specific attribution by functional area includes: LTC William H. Pentz, USA, "Designing for Quality"; Gerald J. Chasko, "Designing for Reliability and Maintainability" and "Designing for Specialty Requirements"; and LTC Donald T. Ostlund, USA, "Design-to-Cost."

The research that developed the acquisition life-cycle technical activities chart providing a summary perspective of product definition in the technical management process was initiated by R.M. Stepler. His assistance in the research and co-authorship of "Balancing on the Technical Manager's Tightwire" are greatly appreciated. Paul J. McIlvaine, TMD department director, provided the organization and encouragement to focus the design activity. He initiated the research that developed "A Focus for Computer-Aided Technical Management" and he tri-authored that paper which forms much of the background and integration material. The other tri-author, Eric P. Taylor, also deserves recognition for his major contributions to the investigations and conceptual development.

Finally, the collation and editings of this type of document requires a great deal of professional expertise and patience. The staff of the DSMC Publications Directorate deserves the most thanks.

TABLE OF CONTENTS

INTRODUCTION

Defense systems are developed and operated over a long life (20 years and more). They include complex products supported by technical data, facilities, supplies, support equipment, software, and trained personnel (Figure 1). Definition of these systems represents a significant design challenge for Department of Defense (DOD) managers. The challenge is to provide the right talent, tools, and expertise to do the job and then to direct the definition of the product which represents the best trade-off among the often competing life-cycle requirements of the product. Requirements include broad terms like system effectiveness, life-cycle cost and schedule for full system support and more definitive terms like reliability, unit production cost and performance.

Evolution of the design complexity required to optimize defense products has altered the central nature of the designer. Early in the century as the complexity of products increased and the production function became specialized, increased detailed information was required for other specialists to use. This often resulted in more drawings with greater detail. Hence, a division of labor was created so that draftsmen could assume some of the load. Thus, more time was provided for the designer to create because the product could be delegated for detailing.

Mid-century, overlapping the productivity improvement (more creative effort per time dimension) of designers, the complexity spawned technical productivity (increased specialist output per time dimension) through the creation of

Figure 1. The System

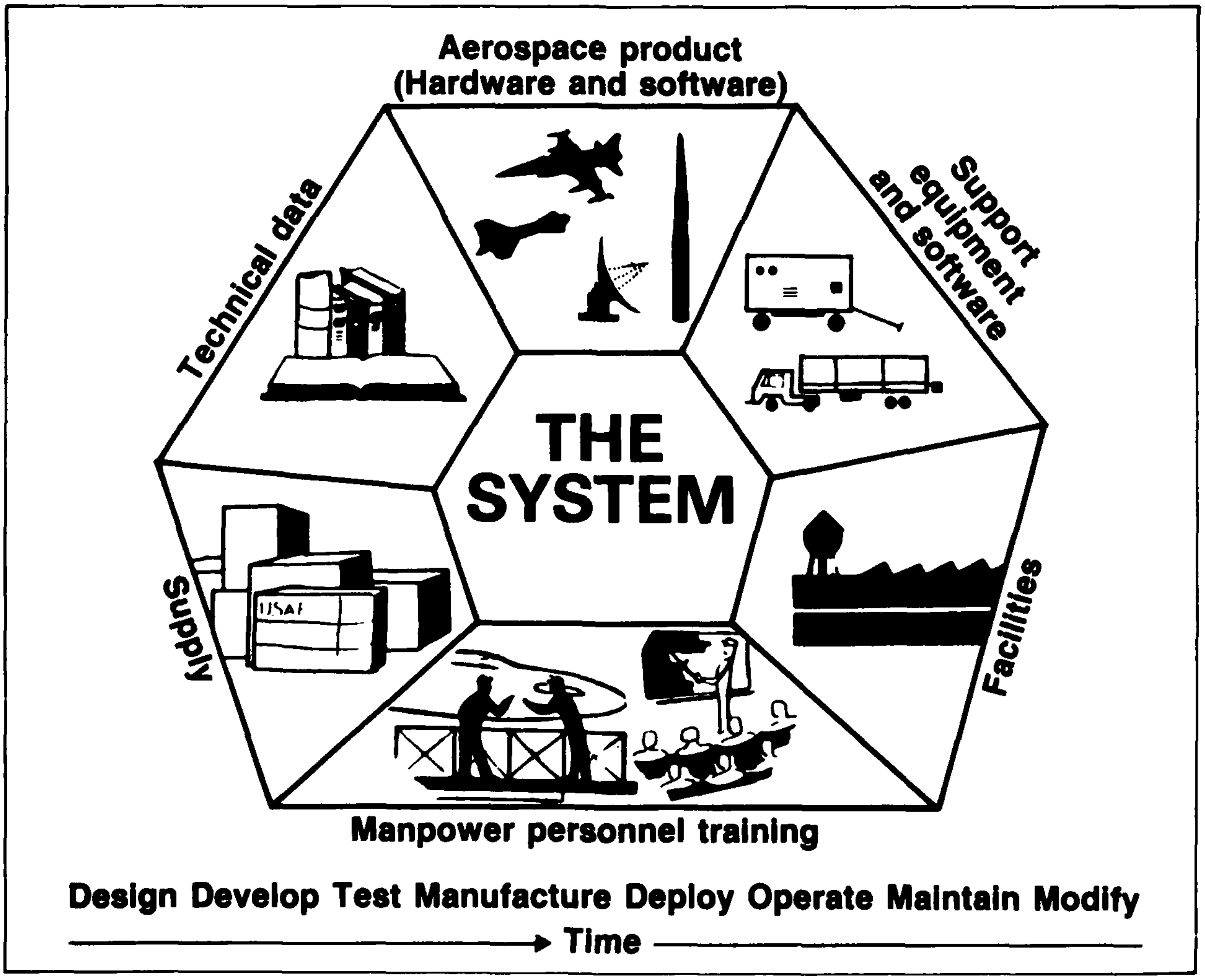
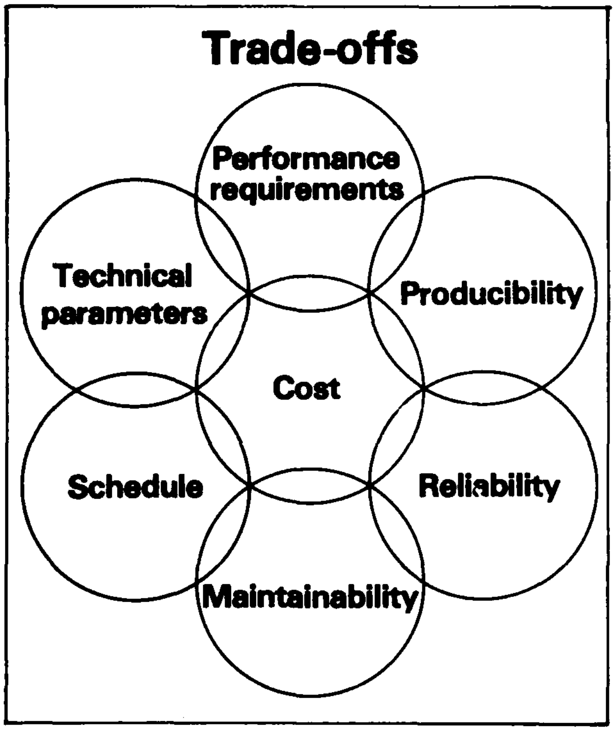


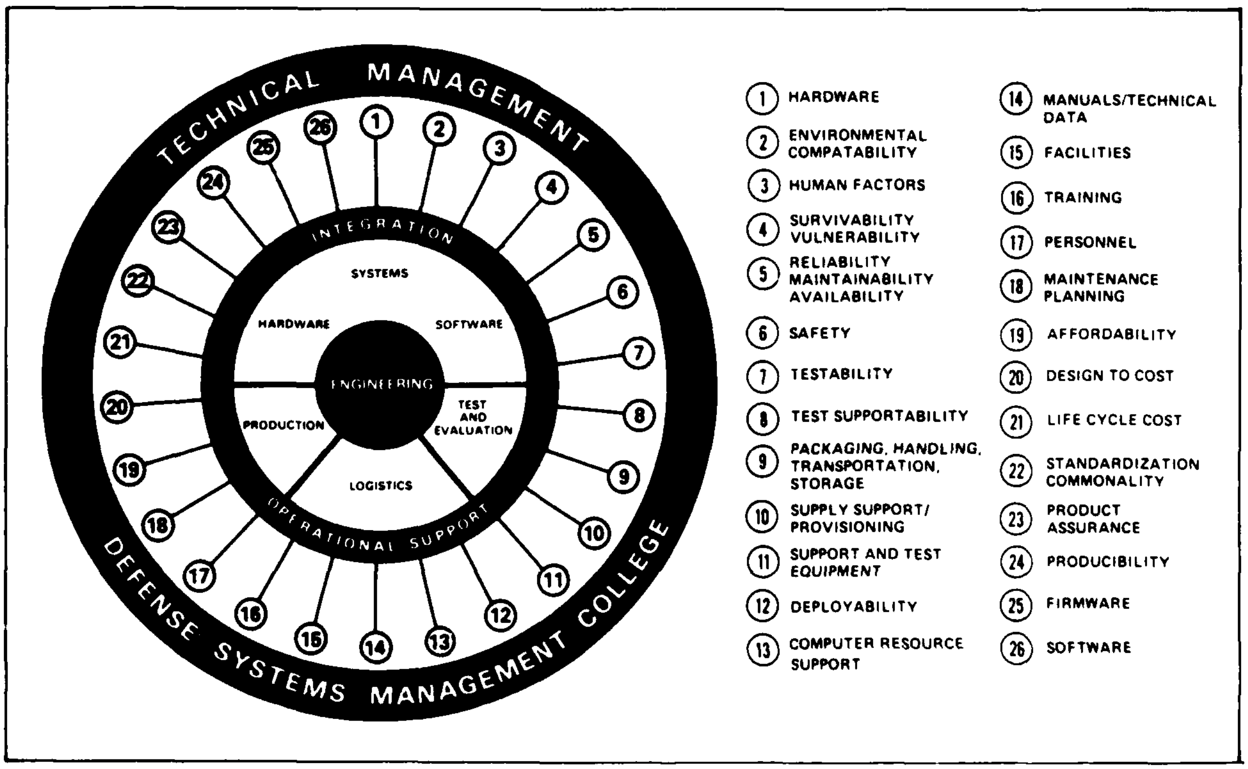
Figure 2. The Name of the Game



technical "cults" (systems engineers, analytical groups, industrial engineers, producibility engineers, logisticians) which displaced the central nature of the designer reducing the function nearly to coordination rather than creation. Of course the reason was that designers did not have the required broad background which encompassed all the skills required for system development. The management approach was establishing a design department and other "ility" departments all tied together by a bureaucratic arrangement for drawing approval which "assured integration." Nevertheless, the designer worked to incorporate all the inputs in as near real-time as possible and developed personal closeness and identity with the design as it progressed through manufacture, test, delivery and operation.

In the 1980s, computerized aids have continued to improve design process productivity. But an even greater benefit is now available if the computer aid can support an effective centralized and coordinated integration of DOD product definition requirements without losing the designer's "touch."

Figure 3. The Most Significant Acquisition Elements



Life-Cycle Design

Designing in the defense system arena is a challenging occupation requiring skill and knowledge. There are literally thousands of specifications and standards which capture many years of lessons-learned and which must be considered and appropriately streamlined/tailored for the product requirement. When coupled with high technology performance requirements, fitness for service use, scheduled deliveries, and budget constraints the design task is awesome.

In the final analysis, detail design is a big trade-off game with cost at the center (Figure 2). The designer must face interrelationships of "ilities" that have reached 26 at the Defense Systems Management College (Figure 3). For convenience these are captured herein under the topics of quality, reliability and maintainability, production, special systems requirements and cost.

Then the life-cycle cost trade-off process raises questions like:

—Does better quality cost more?
—Does better supportability cost more?
—Does better producibility cost more?
—Does better reliability cost more?
—Does better maintainability cost more?

Moreover, are questions like these true individually and/or collectively?

Responses usually include statements like "it all depends on how well the designer balances unit price and life-cycle cost" and "not necessarily depending on how well the designer integrates the "ilities" (Reference a). The fundamental point is that the terms producibility, quality, reliability, maintainability, and supportability are *not* mutually exclusive in design terms and can (in fact, should) reinforce each other in systems design. The fundamentals of "designing for..." are addressed separately in the following sections but recognize that integration and iteration should occur through a schematic like Figure 4, whether computerized or not. This concept is explained in "The State Of The Art In DOD Product Design," the last section.

Designing for Performance

There are as many "methods" for product design as there are products, and probably as many as there are designers. This description is intended only to provide a framework for discussions of important considerations in product definition.

The designer starts with the specification and proportions a solution (a first cut in the designer's mind) best meeting the requirements. For large products like airplanes and ships, the first definition begins with small-scale layouts that lead to roughing in state-of-the-art subsystems, and refinement of external configuration through model testing. For some products, the creative process starts better with block diagrams, proceeds to circuit schematics, and ends with packaging.

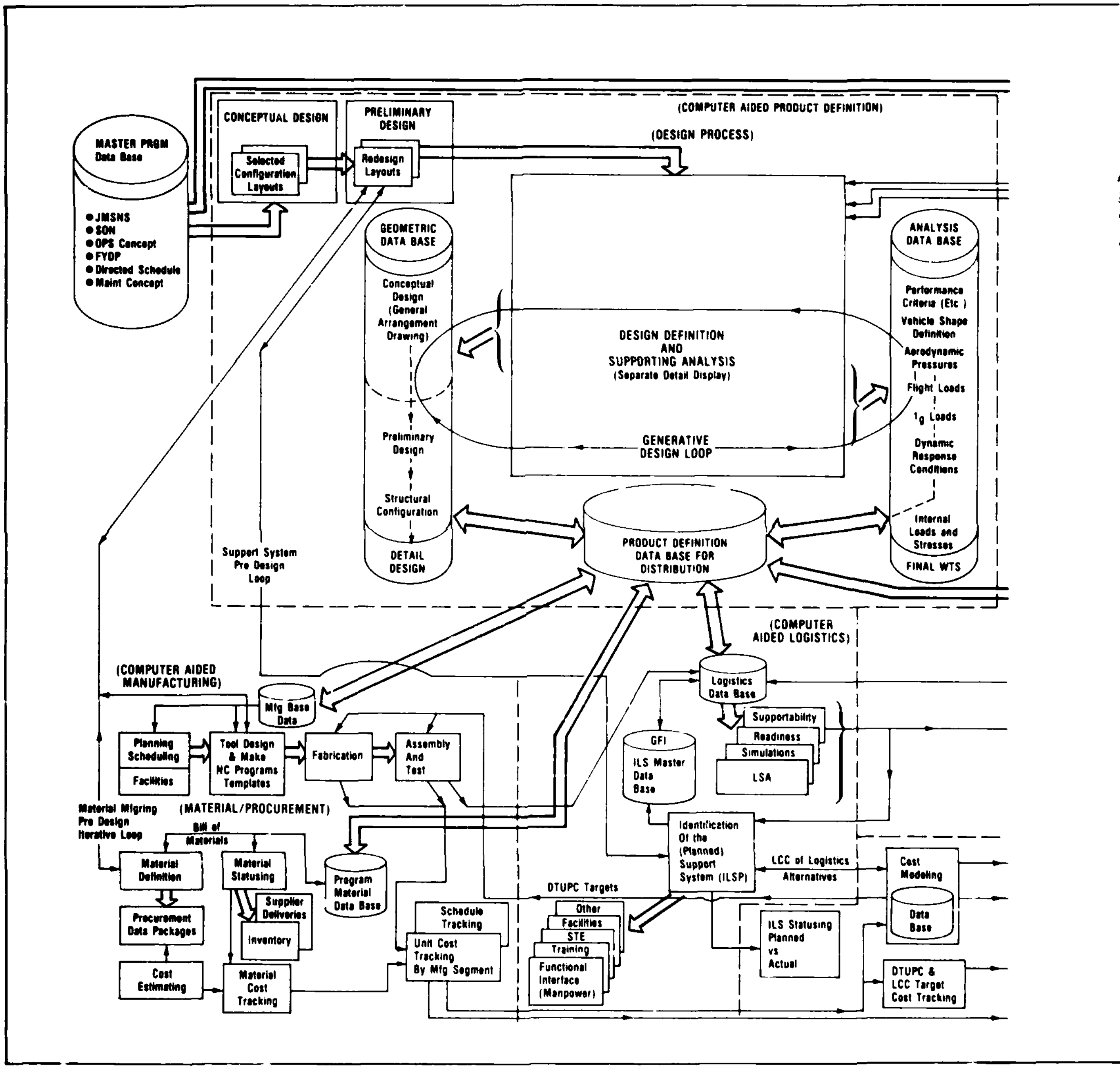
During the design phase where there is a relatively low percentage of life-cycle cost, decisions will be made that lock in approximately 85 percent of the life-cycle cost (Figure 5). Even during initial creative efforts, the mind-set of the designer will have an impact on the life-cycle cost.

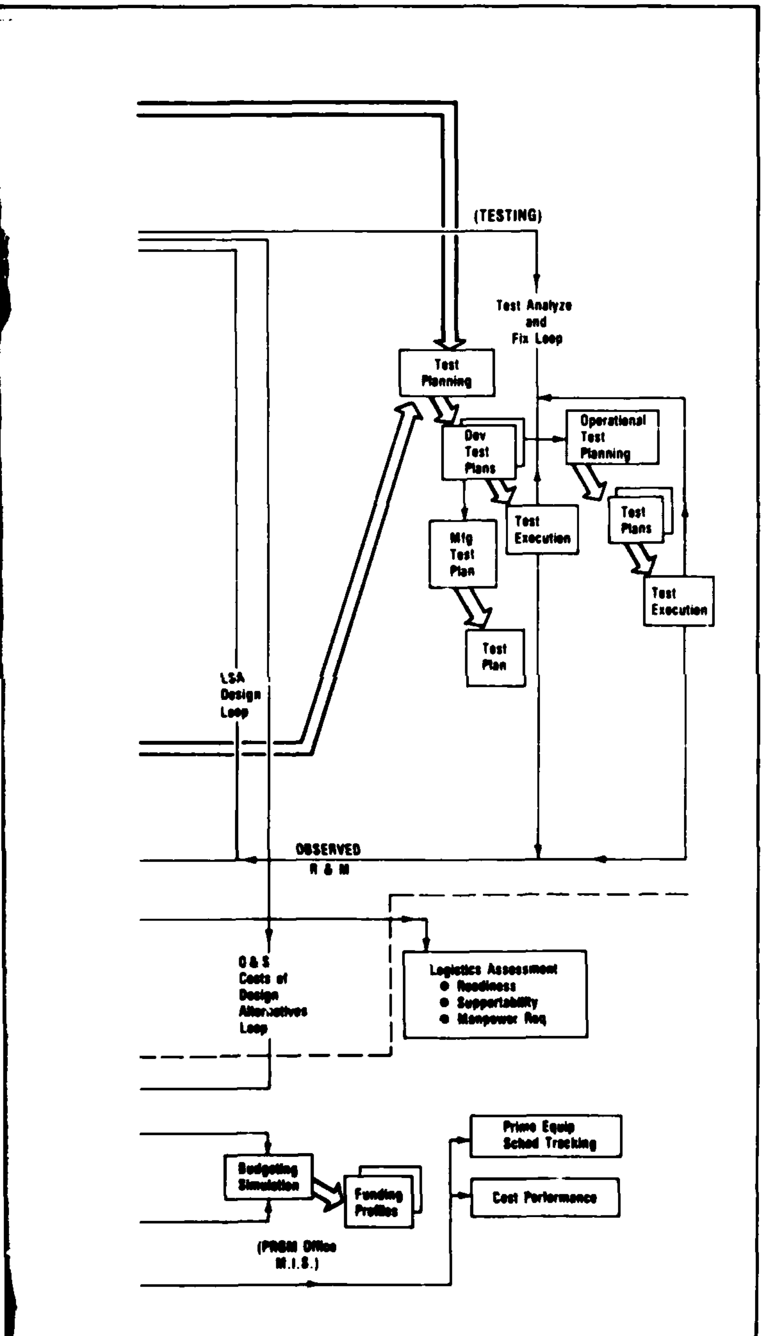
When the design is fluid, trade-offs are in progress to optimize performance, alternatives are in evaluation, and minds are (at least relatively) open to suggestion, it is the best time to incorporate life-cycle design requirements. When results begin to show a particular configuration meeting the performance goal, that configuration becomes difficult to change. The design activity fears that changes to accommodate the "ilities" might deteriorate the performance which is the first evidence of program acceptability. Performance preoccupation is a worse influence when test results indicate a performance problem because then resources and attention are drawn away from life-cycle design. This is a well-known trap; product development is driven by performance requirements, performance is typically the first parameter tested and performance test results set the tone for the development cycle. Performance is important and may be overriding, but early in the program, life-cycle design characteristics should be given fair consideration in the design balancing act.

Designing for Quality

The Department of Defense (DOD) quality program is built upon three mutually supportive objectives; quality of design, quality of conformance, and fitness for use. Supportive in this case contains the implication of integration. A point of view narrowly focusing on the topic of this section is that

Figure 4. Computer-Aided Technical Management





quality of conformance and/or fitness for use of a product are influenced by the quality of the design.

In discussing quality, it is important to distinguish between concepts of grade and consistency. Fast food chains concentrate on providing the food to you the same way every time, wherever you are (consistency). Whether fast food is the grade you want is another matter. Design for quality largely relates to grade, but you should recognize that consistency and successful real-world use are also dependent upon design.

Specifics for "designing in quality" are emerging but not yet captured in a single guide. The following narrative provides a contemporary view of the subject.

The basic policy of DOD is to hold the contractor responsible for quality of the product through a quality assurance program. Quality assurance is defined in DODD 4155.1 as "a planned and systematic pattern of actions necessary to provide adequate confidence that material, data, supplies, and services conform to established technical requirements and achieve satisfactory performance." This clearly calls for a plan and actions. Suggested fundamentals relating to design are shown in Figure 6 (Reference b).

The plan and actions will be based on the quality requirements. Specifically, the designer must understand the characteristics and/or conditions that represent the greatest stress to the product (Footnote 1). Given the most stressful environment(s), the designer can evaluate intended usage and then proportion the elements to operate at stress levels conducive to attaining the desired equipment life.

Footnote 1. An example; define a vessel to hold fluid at the dinner table—commonly a "glass." It has all the properties you may desire: ease of cleaning, holds the material fluid, and allows the user to see what's in the container. However, Its intended use does not represent its most stressful environment. Storage of glasses in a stack and cleaning of glasses in a dishwasher cause more stress than its "operational" environment of table-top use.

Figure 5. System Life Cycle

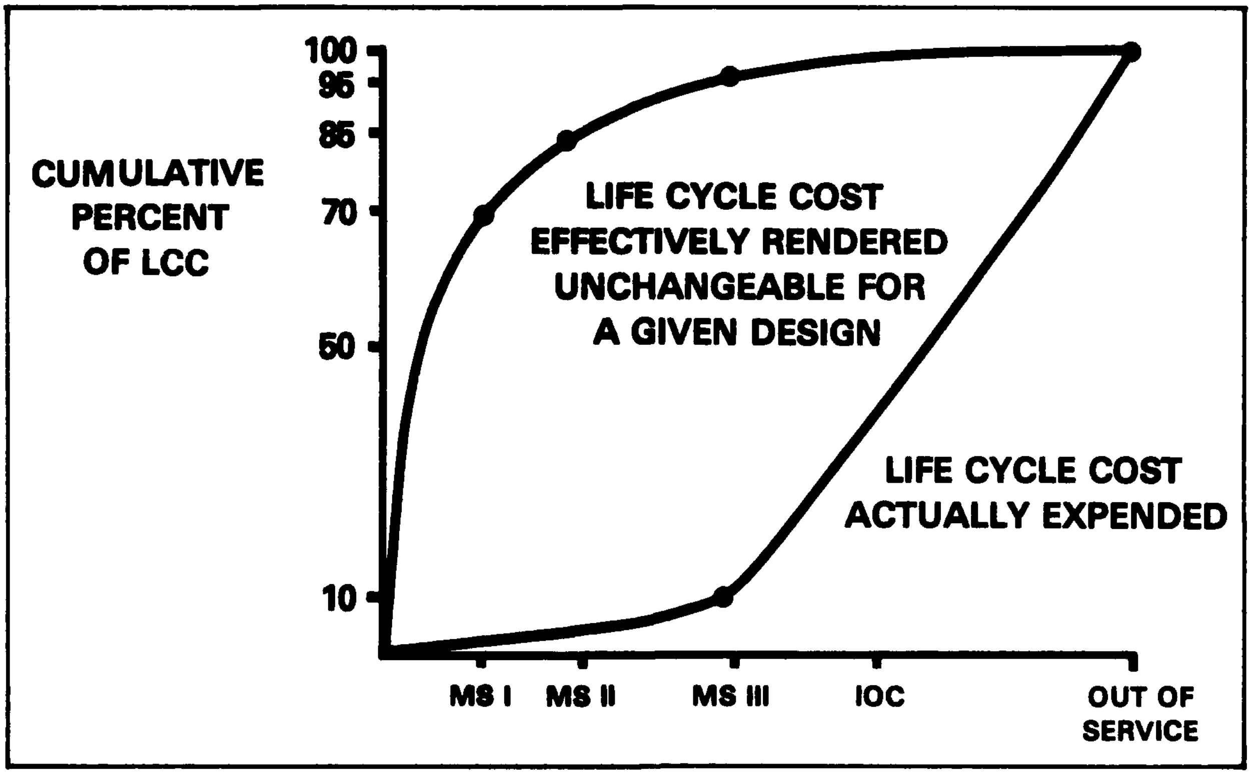


Figure 6. Material Acquisition Fundamentals

- Mission Profile Definition/Environmental Requirements
- Stress Analysis
- Derating Criteria
- Worst-Case Analysis
- Sneak Circuit Analysis
- Prediction/Allocations
- Failure Modes & Effects Analysis
- Test, Analyze, & Fix With Closed-Loop Reporting
- Design Reviews
- Mission Profile Qualification Test

Included in the analytical effort are definition of a worst case and tolerance for the outcome. Where appropriate, sneak circuit analysis should be conducted so that alternate paths of function will not permit an undesired product action. This is generally conducted by a separate set of "design eyes" for electronic circuits. Other "ics" (mechanics, pneumatics, hydraulics) may require "sneak path" analysis.

In complex products it is necessary to recognize the potential for error, and plan for an orderly test and evaluation of the design quality. To this end, predictions and allocations relating performance parameters are required for monitoring the quality of the functional analytical tasks, and to supply basic data for system analysis tasks like failure modes and effects. This extends the analysis to the consequences of unplanned events which may subject the system to a more severe environment than specified in the mission profile.

A test, analyze, and fix cycle with closed-loop reporting is required during development to assure

that all of the above design for quality actions have been successfully accomplished; or, where failures occur to provide an orderly basis for corrective action.

The progress of the design will be monitored through the series of design management reviews generally conducted as part of the defense system acquisition review process. The design for quality actions described in this section should be monitored at every review opportunity. Specific definition of the design for quality plans, actions and reviews can be required under contractual application of MIL-Q-9858A.

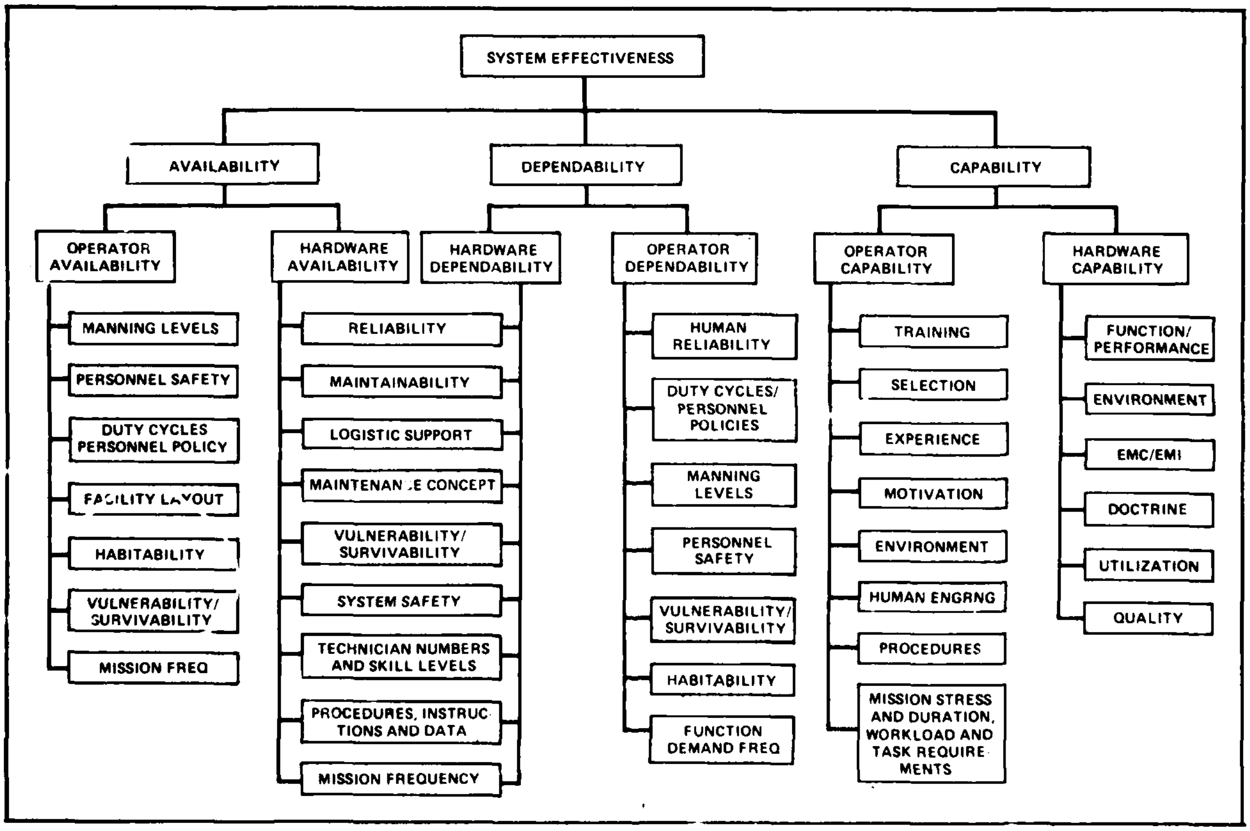
In summary, there are some specific program office actions that will ensure design for quality. Clearly define the critical mission profile elements, the environment in which the item is to operate and, where necessary, provide criteria such that elements of the system operate at a stress level assuring the necessary operating life. Then, monitor the contractor action to assure a rigorous application of the principles identified in Figure 6. Finally, a major milestone for the product is the mission profile qualification test which should provide confidence that the design for quality effort has been successful.

In this section, the term reliability has not been used purposely because a separate "design for" has developed for reliability and maintainability, the subject of the next section. Since one way of looking at reliability is that it is the time extension of quality (Reference c), some of the approaches to designing for reliability necessarily relate to designing for quality. This overlap will provide an opportunity to cover more detail.

Designing for Reliability and Maintainability (Reference d)

The references for this section provide basic definitions and define policy and programs for achieving DOD objectives. This section provides a focus for what the designer should do to meet the objec-

Figure 7. System Effectiveness



tives. First, there is recognition that reliability and maintainability are related; e.g., how often must I fix it? Second, there is recognition that each term stands alone; how predictable is mean time between failure and how long does it take to fix it? Programs for the respective subjects are covered in MIL-STD-785 and MIL-STD-470. But, the bottom line is that system effectiveness and cost are the drivers in design decisions. The following discussion addresses reliability and maintainability design interaction and functional design details through the system approach, using system effectiveness and life-cycle cost as measures for definition and tradeoff (Reference e).

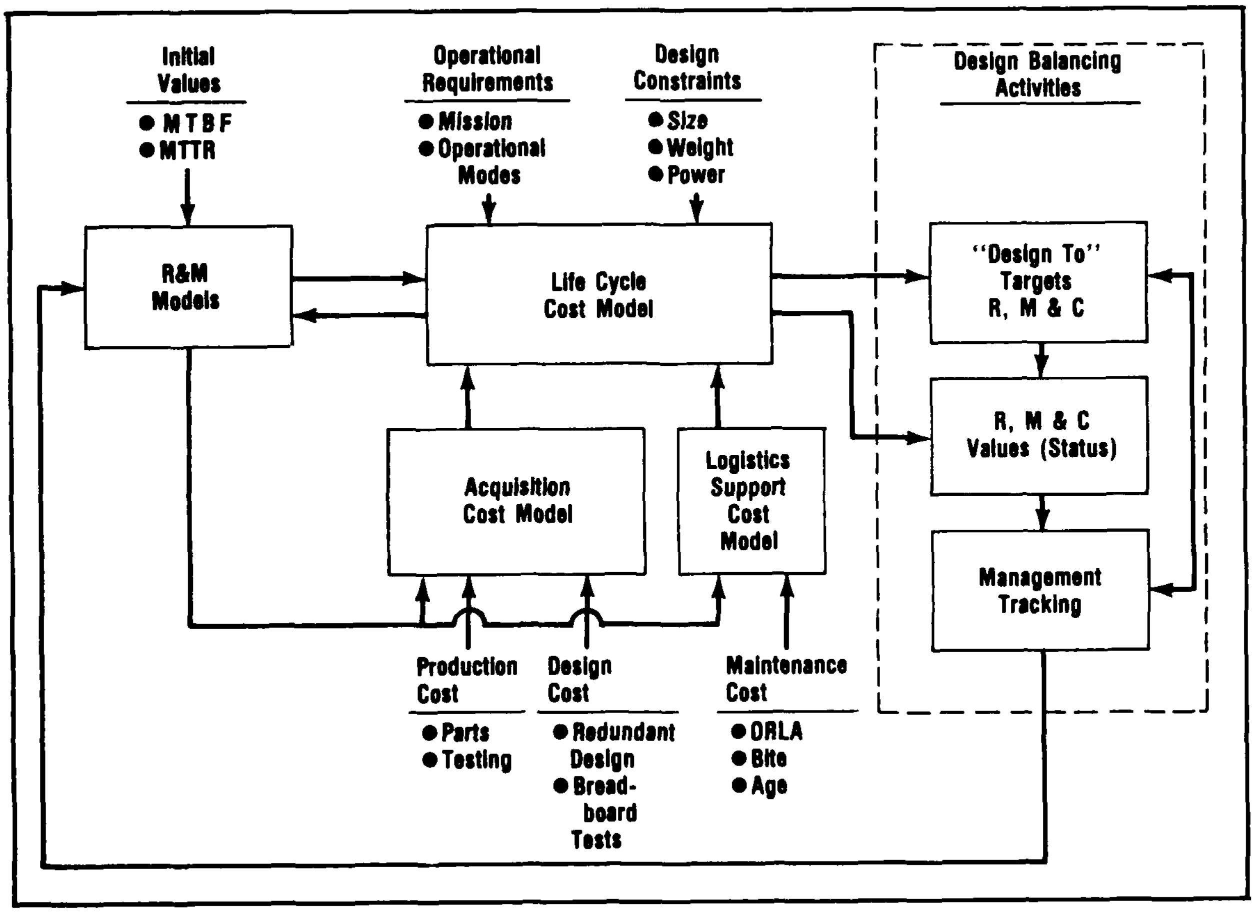
System Effectiveness and Life-Cycle Cost Considerations

The emphasis on capability (performance) has often overridden reliability, maintainability and cost considerations. This led DOD to state that "Improved readiness and sustainability are primary objectives of the acquisition process. Resources to achieve readiness will receive the same emphasis as those required to achieve schedule or performance objectives" (Reference f). To meet this need, the designer must structure a balanced approach which considers system effectiveness and life-cycle cost.

The elements of system effectiveness arrayed under its factors—availability, dependability, and capability—are shown in Figure 7. Definitions for important terms are provided in Appendix A as background for the following discussion.

Figure 8 presents an overview of a methodology to balance cost considerations during reliability and maintainability design balancing activities. The figure shows the life-cycle cost model as the vehicle by which estimates for operation, performance, R, M, and cost are traded off to obtain "design to"

Figure 8. R&M And Cost Methods



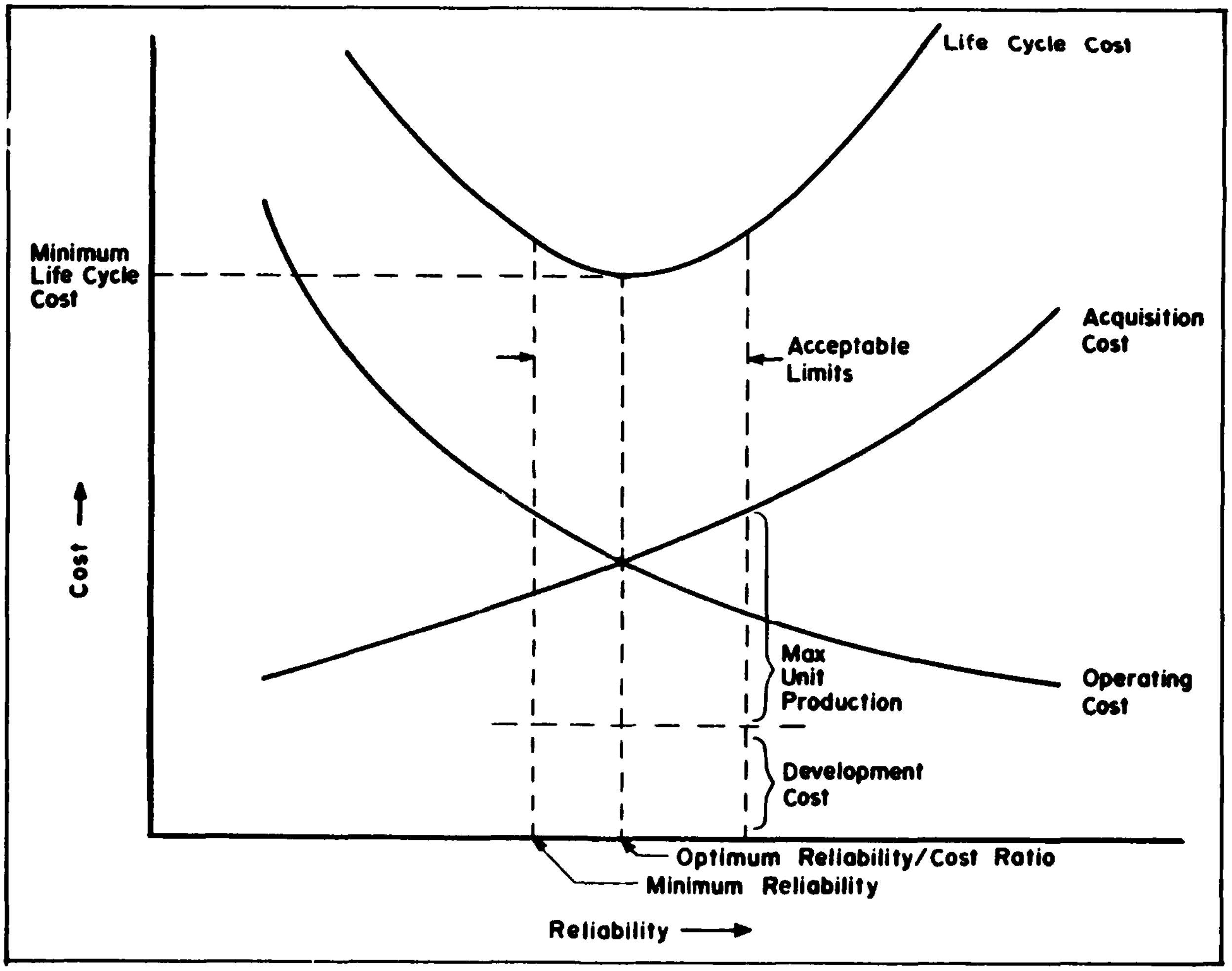
target goals which collectively represent a balanced design. This life-cycle model includes submodels which are representative of acquisition cost and logistic support costs, subject to the constraints of functional objectives and minimum performance requirements. Defining the limits for trade-off of R and M parameters is critical.

The concept of availability is useful for R and M trade-off studies. Consider that over long operating periods, the availability of a system with zero warning time can be expressed as a relationship between uptime (reliability) and downtime (maintainability). Details and rationale for this approach are presented in Appendix B.

Thus, an availability assessment can provide a measure of total equipment performance and is very useful when performing R and M trades. For example, the relationship provides a dimension to evaluate the alternatives of designing for high(er) maintenance. That is, should the design pursue a relatively high MTBF, or design ease of maintenance into the equipment that would result in a low MTTR.

Frequently, the most practical way to achieve a high probability of adequate system effectiveness is to enhance the design for reliability with a design for efficient and rapid repair and a high degree of maintainability. Quantifying these factors in terms of availability provides an insight into the effectiveness of trade-offs and demonstrates numerically the impact of variations. This approach also increases design linkage with effectiveness of the R and M design and the complementing logistic support factors.

Figure 9. Cost versus Reliability



Cost must also be considered in this trade-off process. For this purpose, additional relationships are developed which define how cost changes as reliability or maintainability are varied from a baseline. For example, as a system is made more reliable the operation cost should decrease since there are fewer failures to fix. At the same time, it is anticipated that acquisition cost (both development and production) will increase to attain higher reliability in the system. At some point each acquisition dollar spent on increasing reliability will result in one dollar saved in operating cost. This point represents the reliability for which total costs are minimum (Figure 9).

Caution: There is a respected body of opinion in support of the principles defined in Figure 6 and expanded in Reference b which states that this general cost approach "casts reliability in the role of a cost driver and nothing could be further from the truth. I've worked in it too long only we didn't call it reliability; we called it engineering. We didn't call it any of the acronyms that we now call it and we designed for what we call operating life." Figure 9 is provided herein to show a general thought process about cost which can link reliability and maintainability. The reader should recognize that there is a strong linkage between quality improvement and productivity; that is, a potential for *reduced* acquisition cost as quality improves. The engineering principles of detail design for quality introduced in Figure 6 will be restated and applied to design for reliability in this section.

Although data are limited early in the program, cost goals and minimum acceptable performance should be established early (in the conceptual phase). The primary purpose of these estimates is to provide management with initial visibility so that the design configuration can be adjusted to provide the cost-effective minimum within the constraints imposed and considering engineering balance. Then, trade-offs will be made over the life of the system. During early program phases, historical parametric data will be used to proportion the system. Refined analysis and early tests should be used to verify operating and support costs as well as the associated research and development costs (this generally will verify that the significant cost-drivers in operation and support are reliability, modularity, fault isolation, sparing, and manning).

Data banks must be updated to provide the most accurate parametric estimating data for items such as scheduled and unscheduled maintenance manhours, adequacy and utility of support equipment and technical manuals, diagnostic testing, and training. During early development, many alternates are still under consideration and many data items remain rough estimates. But when a prototype design appears, more accurate logistic and support costs can be estimated. Then, trade-offs can be made with increased confidence in the following areas:

* Improved/increased test equipment to reduce maintenance manhours and/or schedule span time
* Reliability improvement (and/or growth) to reduce spares and repair actions
* Maintenance facilities and manhours to reduce logistics delay time
* Spare inventory to reduce logistic delay time.

Then, cost targeting can be expanded to include requirements on the number of operating and maintenance personnel permitted, support equipment costs, the number of line items permitted in inventory, and the impact of fault detection and isolation. Throughout the cost analysis, the following questions should be addressed:

(1) Does the latest design iteration meet the effectiveness and cost goals?

(2) Do alternative designs exist which can further minimize cost of ownership and enhance system effectiveness?

Once a design proceeds to detailing, trade-off analysis can follow in more detail. Now, the impact of changes in parameters like part quality, redundancy, component reliability, and producibility methods can be analyzed. Then, it becomes possible to identify high-cost areas and develop alternatives to reduce the cost while the design is in a relative fluid state.

Establishing Reliability and Maintainability Requirements

Reliability and maintainability begin with realistic and achieveable requirements established jointly by the military user and the developer in the following manner:

* Evaluate the reliability and maintainability of (similar) systems in the field to establish current levels and improvement trends (see Figure 10)

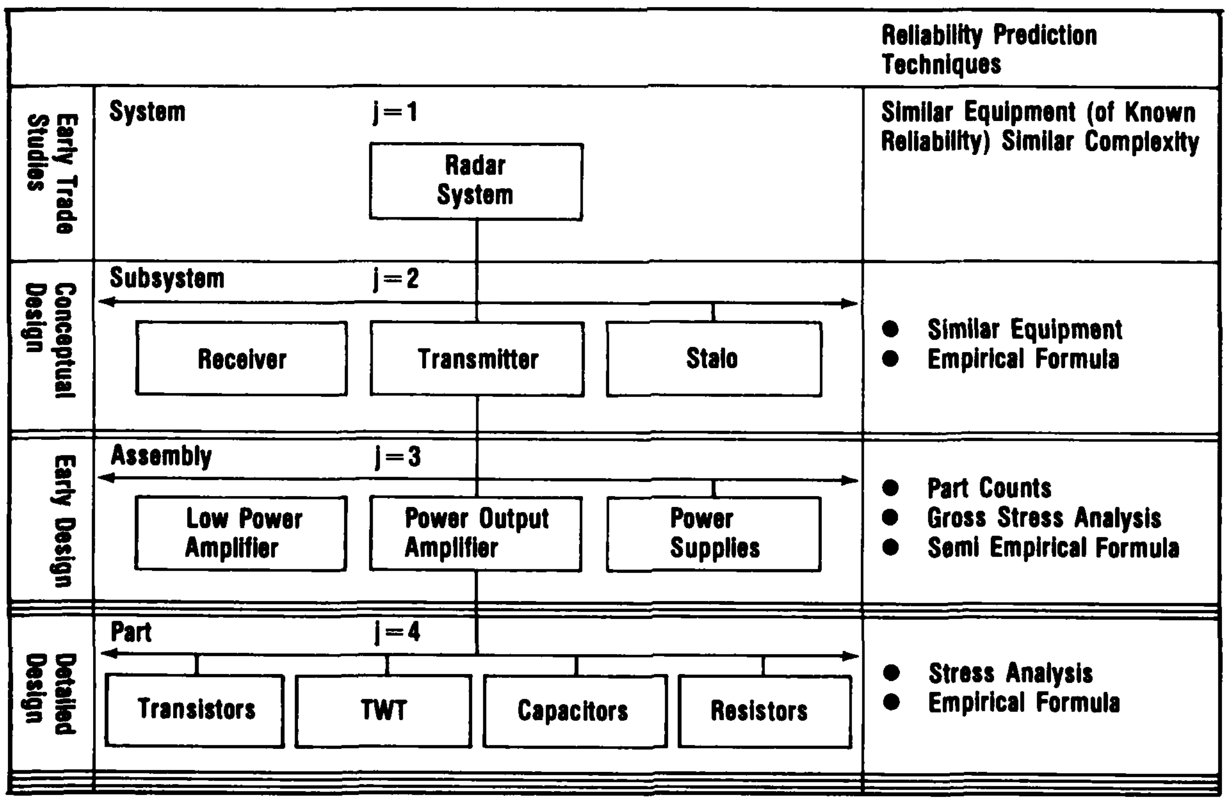
* Conduct system trade-off analysis involving R and M levels, effectiveness, and logistic functions to establish tentatively the needed and affordable R and M level

* Assess the tentative requirements for feasibility of attaining the desired R and M goals, of the schedule in striving for the goals, and of related functional implications such as the ability to determine by test that the equipment has met the R and M goals

* Establish specified values for R and M. These likely will be single-point values to be used in design of the system, but certainly will have some tolerance related to the maturity of the system design and the supporting data base. The analysis of these design points should provide insight for determining if incentives to do better may pay off in lower life-cycle cost, and/or if there is, or should be, a tolerance for doing less well.

To reiterate the engineering principles defined in Figure 6, the most difficult but required input for determining R and M parameters is defining the mission profile and the environment. What is the system to do, in what environment, for how long?

Figure 10. Radar System Hierarchy (partial listing)



R and M Activities

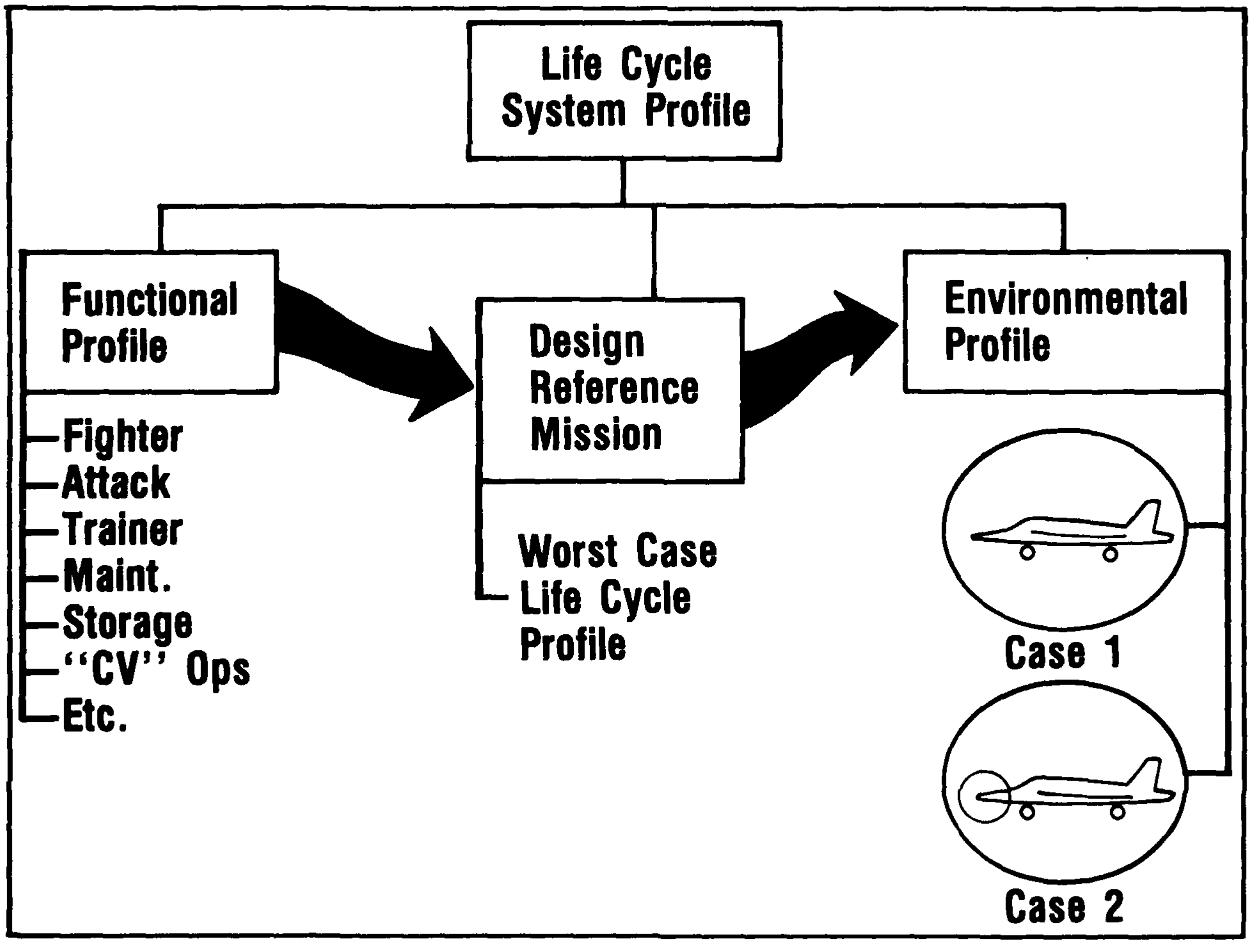
The development of an R and M program requires: understanding the system requirements (Figure 11), allocation of R and M to each system element (Figure 12), developing a design philosophy emphasizing R and M program elements (Figures 13 and 14), developing test criteria that verifies the design and provides for growth (Figure 15) and, finally, planning for the process to sustain designed (inherent) R and M values (MTBF, MTTR) during production and deployment.

A conservative philosophy stressing the use of proven hardware, simplicity, and R and M requirements suited the operational needs will reduce risk, improve R and M, and lower operational and support costs; but, it may not permit stretching the state of the art, thus achieving the desired effectiveness. Whether the conservative approach will meet the goals, or whether it is necessary to push the state of the art, if cost is to be attained effectively, R and M requirements must be streamlined to meet the program needs.

Regardless of philosophy, having selected a source capable of the desired emphasis on design for reliability and maintainability, the following is applicable to all programs:

* Contract for reliability and maintainability
* Design to minimize failures and improve readiness
* Test to verify the design
* Sustain reliability and maintainability in production and service.

Figure 11. Understanding System Requirements



Contract for Reliability and Maintainability

After R and M requirements have been established and allocated to subsystems and elements, the apportioned values (MTBF, MTTR) should be included in appropriate sections of procurement specifications, critical item specifications, and contractor end-items specifications.

The designer must understand every requirement the system must meet and understand where and if trade-offs are desired/permitted. In some cases, then, the contract/specification will include required value(s) and one or more alternative(s). Alternatives may be attractive because they offer reduced cost, or because they represent an attractive trade of resources. In the latter case, the contract must define the basis for pursuing alternatives and any incentives for accomplishing improved cost and/or system effectiveness.

Design to Minimize Failures

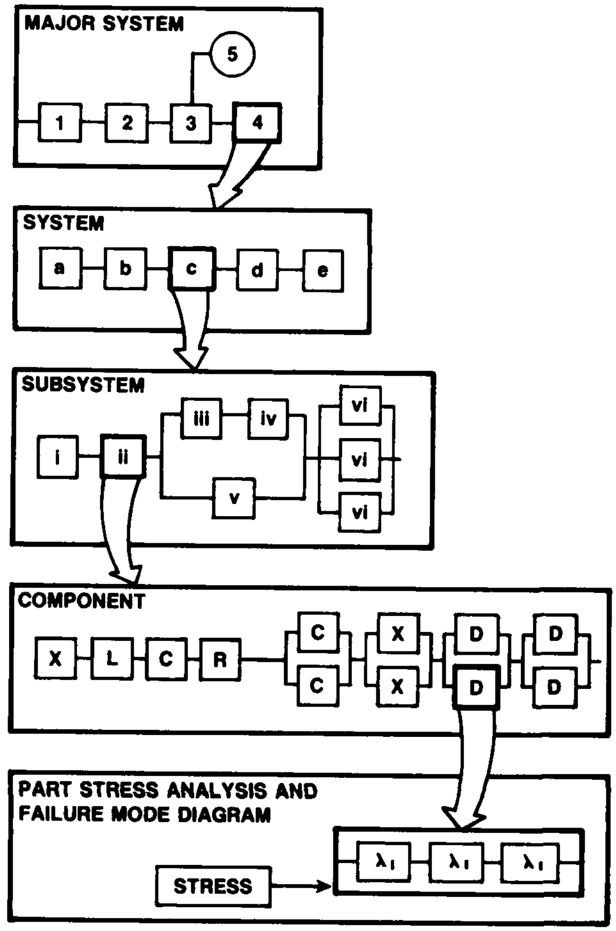
Techniques for designing to minimize failures in DOD products were introduced in designing for quality (Figure 6) and are expanded here (Reference e):

* Mission Environmental/Life Profile
* Derating Criteria
* Stress Analysis
* Worst-Case Analysis
* Failure Modes and Effects
* Sneak Circuit Analysis
* Prediction and Allocation
* Part and Material Selection
* Simplification
* Redundancy
* Ease of Inspection and Maintenance
* Modularity
* Built-In Test/Built-In Test Equipment
* Design Reviews

Mission/Environmental/Life Profile

The most critical information the program office must supply to the designer is in what environment and for how long a product must achieve the required effectiveness. Figures 16 and 17 list en-

Figure 12. Reliability Block Diagram



vironmental factors which must be considered for DOD equipment. The figures also provide brief descriptions of techniques for addressing environmental requirements.

Stress Analysis

"If you're under stress you're not reliable, if I'm under stress I'm not reliable (Reference b)." Stress analysis is fundamental to designing for reliability and there are many texts covering general and specific techniques for analyzing stress. The discipline is increasing productivity and ability to handle complex problems in near real-time through application of computer aids. Under the umbrella of computer-aided engineering (CAE), there is linkage with dynamic simulations and active testing of hardware to establish actual operational stresses more accurately and quickly.

Figure 13. Reliability Program Elements By Program Phase

ELEMENT	LIFE CYCLE PHASE				
	CONCEPTUAL	VALIDATION	FULL SCALE DEVELOPMENT	PRODUCTION	DEPLOYMENT
Requirements Definition	xxxxxxxxxxx	xxxxxxAAAAA	A...............		
Reliability Model	xxxxxxx	xxxxxxxxxxx	xxxxx..........		
Reliability Prediction	xxxxxxx	xxxxxxxxxxx	xxxxx..........		
Reliability Apportionment	0000000	00000000000	00000..........		
Failure Modes Analysis	0000000	00000000000	xxxxxx.........		
Design for Reliability	0000000	xxxxxxxxxxx	xxxxxxxxxxxxx	....	
Parts Selection	0000000	xxxxxxxxxxx	AAAAA..........	....	
Design Review	0000000	xxxxxxxxxxx	xxxxxx		
Design Specifications	xxxxxxxxxx	xxxxxxxxxxx	xxxx...........		
Acceptance Specifications	xxxxx	xxxxxAAAAA	A...............		
Reliability Evaluation Tests	— —	xxxxxxxxxxx	xxxxxxx		
Failure Analysis	— —	xxxxxxxxxxx	xxxxxxxxxxxxx	00000000000	00000000000
Data System	— —	xxxxxxxxxxx	xxxxxxxxxxxxx	00000000000	00000000000
Quality Control		00000000000	xxxxxxxxxxxxx	xxxxxxxxxxx	00000000000
Environmental Tests		xxxxx	............AAA	A............	
Reliability Acceptance Tests		xx	...............A	AA000000000	

First Contract

KEY					
— — — —	Desirable Activity (For Highest Success Probability)	xxxxxxxxx	Very Important Activity (Errors Often Disastrous)	AAAAAAAA	Critical Activity (Errors Usually Disastrous)
000000000	Necessary Activity (Errors Seldom Disastrous)			....	Low Key Activity (To Update Previous Results)

Figure 14. Maintainability Program Elements By Program Phase

ELEMENT	LIFE CYCLE PHASE				
	CONCEPTUAL	VALIDATION	FULL SCALE DEVELOPMENT	PRODUCTION	DEPLOYMENT
Requirements Definition	XXXXXXXXXXXX	XXXXXXAAAAA	A...............		
Maintenance Concept	XXXXXXXXXXX	XXXXXXXXXXX	XXXX...........		
Maintainability Analysis	XXXXXXX	XXXXXXXXXXX	XXXX...........		
Design for Maintainability	0000000	XXXXXXXXXX	XXXXXXXXXXXXX	....	
Maintainability Prediction	0000000	XXXXXXXXXX	XXXXXX..........		
Design Review	0000000	XXXXXXXXXX	XXXXXX..........		
Design Specifications	XXXXXXXXXX	XXXXXXXXXXX	XXX.............		
Acceptance Specifications	XXXX	XXXXXXXXAAAA	A...............		
Detailed Maintenance Plan	——0000000	00000000000	XXXXXXXXX AAA	....	....
Data System		XXXXXXXXXXX	XXXXXXXXXXXXX	00000000000	000000000000
Technical Manuals		00000000000	XXXXXXXXXAAA	....	....
Maintainability Acceptance Test		XX	............AAA	....	

First Contract

KEY			
— — — —	Desirable Activity (For Highest Success Probability)	AAAAAAAA	Critical Activity (Errors Usually Disastrous)
XXXXXXXXXX	Very Important Activity (Errors Often Disastrous)		
0000000000	Necessary Activity (Errors Seldom Disastrous)	....	Low Key Activity (To Update Previous Results)

Figure 15. R&M Maturation Achieved Through Dedicated Test Analysis and Fix Programs

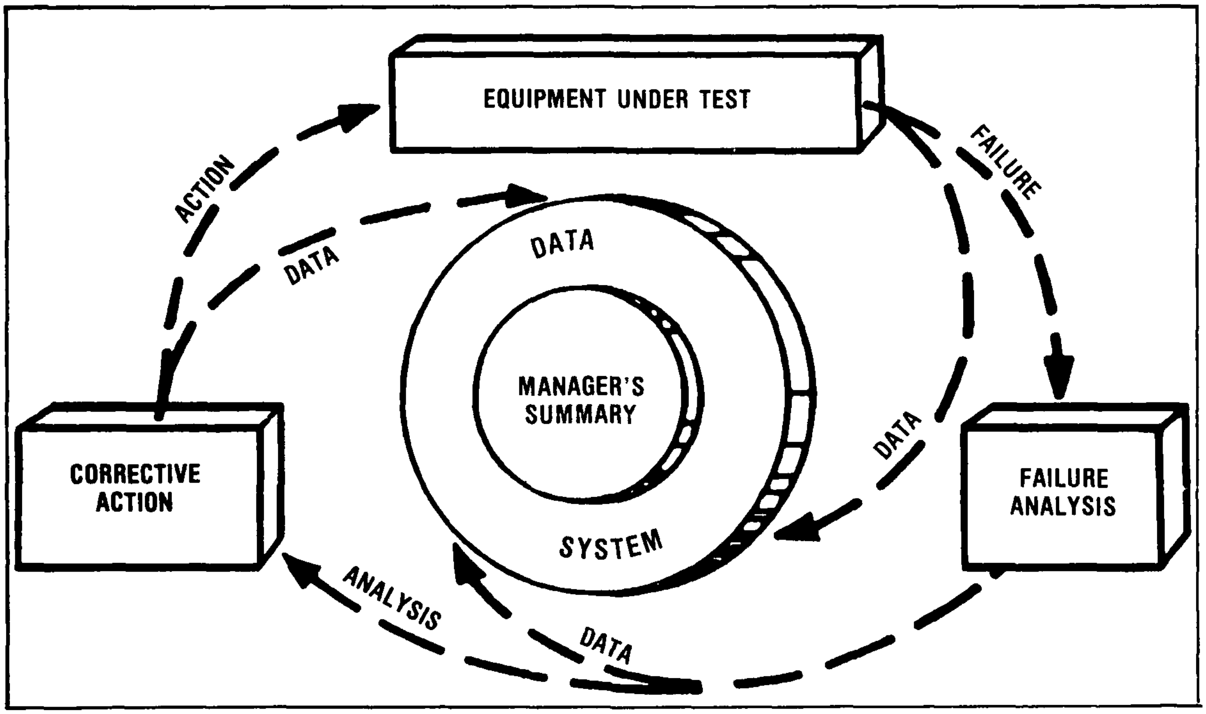


Figure 16. Environmental Stresses, Effects and Reliability Improvement Techniques in Electronic Equipment

Environmental Stress	Effects	Reliability Improvement Techniques
High Temperature	Parameters of resistance, inductance, capacitance, power factor, dielectric constant, etc., will vary; insulation may soften; moving parts may jam due to expansion; finishes may blister; devices suffer thermal aging; oxidation and other chemical reactions are enhanced; viscosity reduction and evaporation of lubricants are problems; structural overloads may occur due to physical expansions.	Heat Dissipation devices, cooling systems, thermal insulation, heat-withstanding insulation, heat-withstanding materials.
Low Temperature	Plastics and rubber lose flexibility and become brittle; electrical constants vary; ice formation occurs when moisture is present; lubricants gel and increase viscosity; high heat losses; finishes may crack; structures may be overloaded due to physical contraction	Heating devices, thermal insulation, cold-withstanding materials.
Thermal Shock	Materials may be instantaneously overstressed causing cracks and mechanical failure; electrical properties may be permanently altered. Crazing, delamination, ruptured seals.	Combination of techniques for high and low temperatures.
Shock	Mechanical structures may be overloaded causing weakening or collapse; items may be ripped from their mounts; mechanical functions may be impaired.	Strengthened members, reduced inertia and moments, shock absorbing mounts.
Vibration	Mechanical strength may deteriorate due to fatigue or overstress; electrical signals may be mechanically and erroneously modulated; materials and structures may be cracked, displaced, or shaken loose from mounts; mechanical functions may be impaired; finishes may be scoured by other surfaces; wear may be increased.	Stiffening, control of resonance.

Figure 17. Environmental Stresses, Effects and Reliability Improvement Techniques in Electronic Equipment (Continued)

Environmental Stress	Effects	Reliability Improvement Techniques
Humidity	Penetrates porous substances and causes leakage paths between electrical conductors; causes oxidation which leads to corrosion; moisture causes swelling in materials such as gaskets; excessive loss of humidity causes embrittlement and granulation.	Hermetic sealing, moisture-resistant material, dehumidifiers, protective coatings.
Salt Atmosphere and Spray	Salt combined with water is a good conductor which can lower insulation resistance; causes galvanic corrosion of metals; chemical corrosion of metals is accelerated.	Nonmetal protective covers, reduced use of dissimilar metals in contact, hermetic sealing, dehumidifiers.
Electromagnetic Radiation	Causes spurious and erroneous signals from electrical and electronic equipment and components; may cause complete disruption of normal electrical and electronic equipment such as communication and measuring systems.	Shielding, material selection, part type selection.
Nuclear/Cosmic Radiation	Causes heating and thermal aging; can alter chemical, physical and electrical properties of materials; can produce gases and secondary radiation; can cause oxidation and discoloration of surfaces; damages electrical and electronic components especially semiconductors.	Shielding, component selection, nuclear hardening.
Sand and Dust	Finely finished surfaces are scratched and abraded; friction between surfaces may be increased; lubricants can be contaminated; clogging of orifices, etc.; materials may be worn, cracked, or chipped; abrasion, contaminates insulations, corona paths.	Air-filtering, hermetic sealing.
Low Pressure (High Altitude)	Structures such as containers, tanks, etc., are overstressed and can be exploded or fractured; seals may leak; air bubbles in materials may explode causing damage; internal heating may increase due to lack of cooling medium; insulations may suffer arcing and breakdown; ozone may be formed; outgasing is more likely.	Increased mechanical strength of containers, pressurization, alternate liquids (low volatility), improved insulation, improved heat transfer methods.

Derating Criteria

The key to reliability and long life is to design for low-stress levels. In electronics parlance, the term "derating" is used to identify the technique for designing to lower-than-maximum-capability parameters (e.g., junction temperatures, current carrying capacity). For structural and mechanical components, the term often used is "margin of safety" (lower stress than maximum capability). The concept is that "working" the components in an easy stress environment leads to high reliability and long life.

In general, the reaction to derating and safety margins is that weight, volume and cost (and other design effects dependent upon these details) suffer. Trade-offs are usually required. The designers challenge is to minimize the impact by using innovative design techniques; e.g., handle heat by proper placement of components or by using natural cooling, provide margins of stress safety by using efficient structures/mechanics and/or efficient materials.

Worst-Case Analysis

Department of Defense products generally are characterized by complexity, high performance, and severe environment. Therefore, it is important to sort out conditions resulting in the worst case for the design, and then to assure that related stresses (component, subassembly, assembly, system) are considered properly in assessments of reliability and life.

Failure Mode, Effect, and Criticality Analysis

This effort primarily supports safety and hazard analysis, but the benefits of looking at the design from this standpoint reach beyond the important aspect of safety. Figure 18 shows one format used. Listed on the figure are nine other important utilities for the process.

Sneak Circuit Analysis

Reference (b) provides a good example of a sneak circuit related to an automobile. "You will notice that if you turn your radio on in a ... car the radio won't play unless the ignition key is turned on. There's an interlock in there to keep you from leaving your radio on and wearing out the battery. Now, with the radio switch on, leave the ignition key off. Reach down and pull out the flasher, then hit the brake and the radio will play. That's an example of a sneak circuit."

The complexity of DOD products creates the potential for alternate paths of functional action. This requires a separate application of rigor in the analysis, a discipline to see that sneak circuit effects do not create unwanted events. The rigor is not only applicable to electronics; complexities in other "ics" (e.g., mechanics, hydraulics, fluidics) and structures require sneak "path" analysis.

Predictions and Allocations

Fundamental to proportioning the elements of the design is predicting the capability of each element and the combination(s) as a system. The technique suggested here addresses reliability and maintainability but is applicable to other "design for" requirements.

Use a work-breakdown structure approach. Given an allocation for the top-level assembly or system, break down the top level into its components and allocate proportions of the goal based on predictions for the capability to design. Of course, this will lead to checking the feasibility of the total goal; trade-offs to achieve overall goals like minimum life-cycle cost in a better way; and, establishing tolerances in the predictions with related risks and alternatives. Then, set up a program to check progress against the allocations through continuing analysis, simulation and/or test.

Part and Material Selection

"Parts are the building blocks of equipment and systems. The inherent or generic failure rates of parts and the design application of parts will principally determine failure frequency, readiness, mission success, maintenance cost, and logistic support cost. Parts which are similar functionally are available with a wide range of inherent failure rates. Depending upon the parts selected, a system of 1,000 parts may have a mean-time-between-failure of 100 hours or 100,000 hours. Established, reliable

Figure 18. Failure Mode, Effect and Criticality Analysis

Ref.		Failure Mode Analysis				Failure Effect Analysis		Criticality	
Designation/ Part Type	Function	Mode of Failure	Mode Freq. Ratio	Part Fail. Rate	Time Req. Per. Miss.	Effect of Failure	Degree of Degradation	Mode	Part

- Uncover parts and materials misapplications
- Identify single-point failures
- Assist in design-simplification efforts
- Identify maintenance-design characteristics
- Support RMA analyses predictions, and allocations
- Assist the spares-selection process
- Identify critical items for configuration control/traceability
- Establish quality inspection points
- Assist in test-program planning
- Support safety and hazard analyses

parts with the best available failure rates cost more to manufacture and test than commercial parts. So the initial cost is higher but the system life-cycle cost may be significantly lower (Reference h)."

Early in a program, parts specialists will establish the program parts selection list (PPSL) which designers use to select standard parts that meet program qualification, documentation, and reliability requirements. Figure 19 indicates considerations for part selection and control, and Figure 20 indicates the breadth of the process (Reference e).

Figure 20. Parts and Materials Control

- Establish parts and materials R&M plan
- Prepare parts specifications
- Review parts selection and application
- Conduct detailed failed parts analyses
- Maintain parts standardization program
- Publish preferred parts lists
- Establish parts screening program
- Establish derating policies
- Conduct parts and materials research

Figure 19. Considerations for Part Selection and Control

a) Determine part type needed to perform the required function and the environment in which it is expected to operate.

b) Determine part criticality.
- Does part perform critical functions (i.e., safety or mission critical?)
- Does part have limited life?
- Does part have long procurement lead time?
- Is the part reliability sensitive?
- Is the part a high-cost item or does it require formal qualification testing?

c) Determine part availability.
- Is part on a Preferred Part List?
- Is part a Standard MIL item available from a qualified vendor?
- What is normal delivery cycle?
- Will part continue to be available throughout the life of the equipment?
- Is there an acceptable in-house procurement document on the part?
- Are there multiple sources available?

d) Estimate expected part stress in its circuit application.

e) Determine reliability level required for the part, in its application.

f) Determine the efficiency of burn-in or other screening methods in improving the part's failure rate (as required).

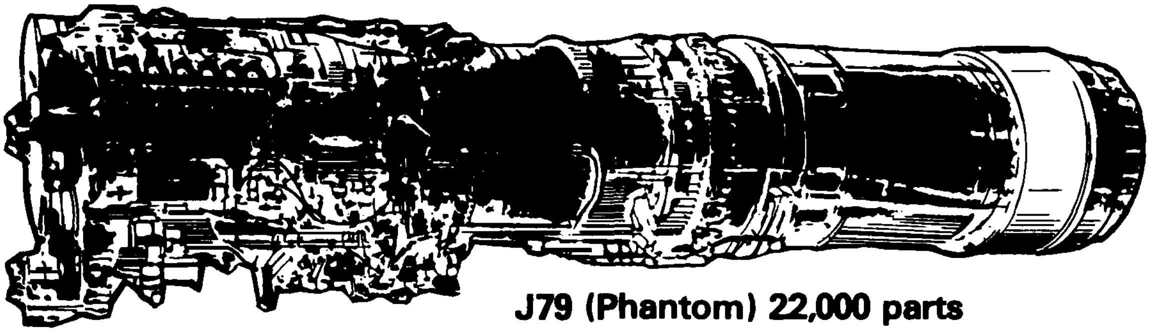
g) Prepare an accurate and explicit part procurement specification, where necessary. Specifications should include specific screening provisions, as needed to assure adequate reliability.

h) Determine actual stress level of the part in its intended circuit application. Include failure rate calculations per MIL-HDBK-217B.

i) Employ appropriate derating factors consistent with reliability prediction studies.

j) Determine need for non-standard part and prepare a request for approval as outlined in MIL-STD-749 or MIL-STD-891.

Figure 21. Engine Design Simplicity for High Reliability



J79 (Phantom) 22,000 parts

SAME THRUST CLASS

- ~3/4 the length
- ~1/2 the weight
- 7700 fewer parts

8 FEWER STAGES

- 7 compressors
- 1 turbine

3 fewer variable stators

SIMPLE GEARBOX

- 38 fewer bearings
- 28 fewer shafts

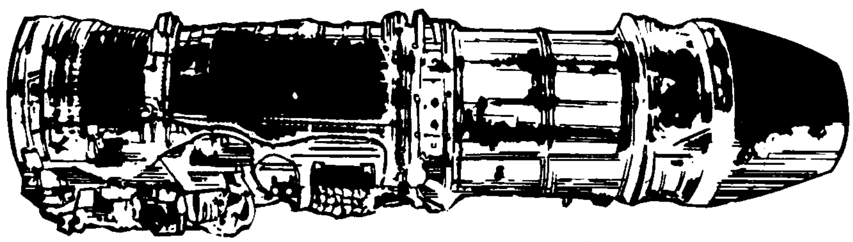
SIMPLE FUEL SYSTEM

- 29 fewer pipes

ONE COMBUSTOR

Liner vs

10 cans



F404 (Hornet) 14,300 parts

And reliability four times higher!

Simplification

Simplicity impacts many of the "designing for 'ility'" topics. Fewer parts means less to build, less to fail, less to maintain, and less to spare. An example of design for simplification is shown in Figure 21. Reference (b) indicates that the goal for the F404 engine used in the F-18 was to contain half the part count of the J79 engine (while achieving the required performance). The figure (21 here, from Reference b) shows that the part reduction goal was not quite attained but a significant reduction was achieved and reliability increased.

Redundancy

Another approach used in effective design is redundancy, the application of added elements (as opposed to simplicity, fewer elements) to improve reliability. The mathematical relationship for reliability and redundancy is shown on Figure 22. This approach falls in two general groups (and combinations), multiple capable elements in operation and switchover. In the former case, a critical function is designed such that two or more elements operating in parallel can each meet the performance requirements. Then, if one fails there is one or more element in place to accept "the load." Another approach provides multiple elements but only single operation until failure which then triggers switchover to another element.

In addition to the two general groups and related techniques of redundancy, another form can exist within normal (non-redundant) design forms. Parallel paths within a network often are capable of carrying added load when elements fail. This can result in degraded but tolerable output. The allowable degradation depends upon the number of alternate paths available. Where a mission can be accomplished using an equipment with degraded output, the failure definition can be relaxed to accommodate degradation. This approach has lead to the concept of "graceful degradation."

The decision to use redundant design techniques must be based on careful analysis. Redundancy may provide the only choice when other methods of improving reliability are exhausted and when methods of part improvement are more costly than duplications. Redundancy may offer an advantage in preventive maintenance considerations. The existence of redundant equipment may allow for repair with no system down time (Figure 23). Occasionally, requirements exist such that equipment cannot be easily maintained (e.g., spacecraft). In such cases, redundancy is often used to extend operating time without failure.

Of course, the application of redundancy imposes penalties which must be minimized through innovative designs and traded off versus increased weight, space, complexity, cost, and development time.

Figure 22. Reliability and Redundancy

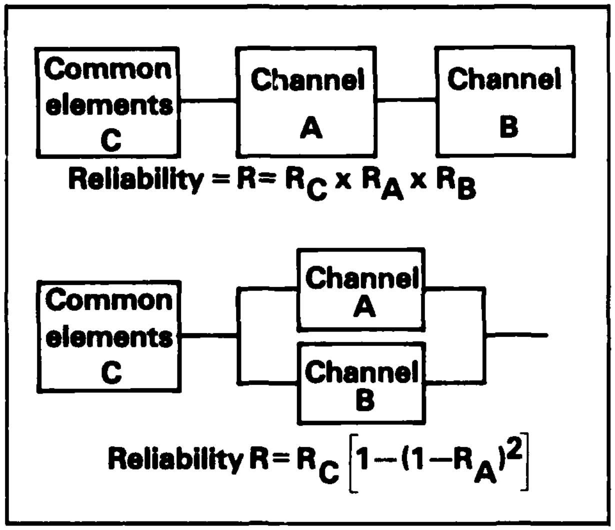


Figure 23. Availability Gain With Repair Capability of Parallel Redundant Element at Failure

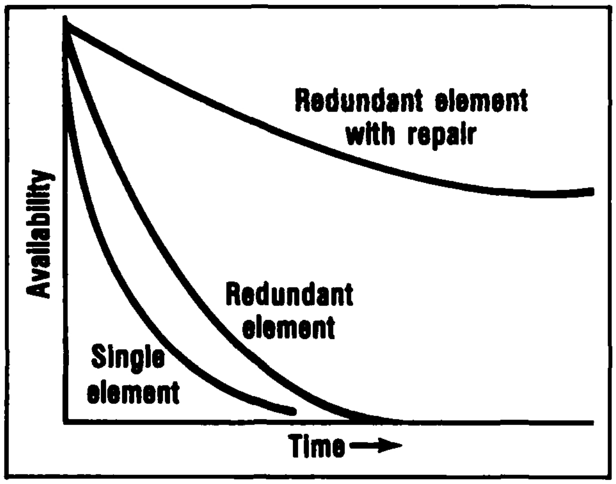
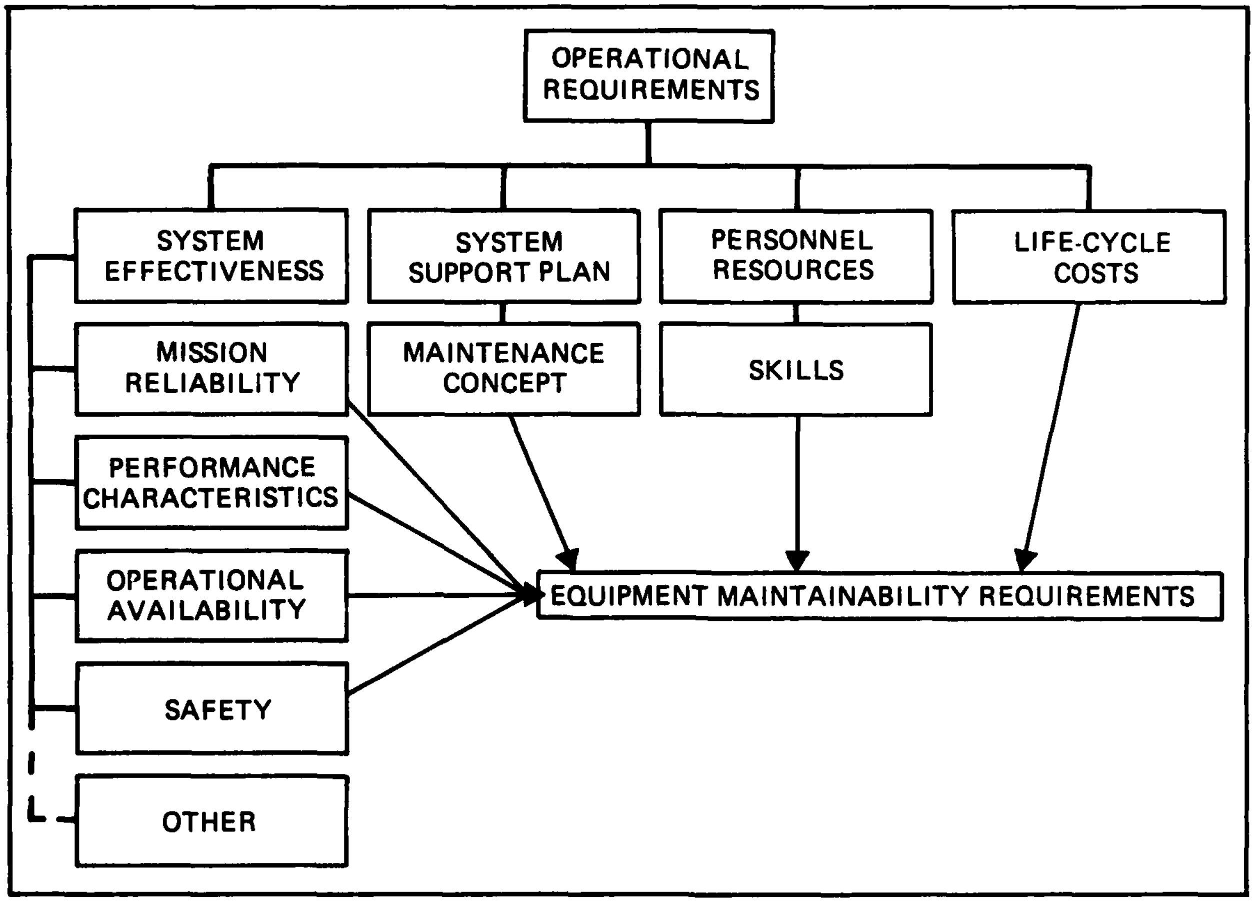


Figure 24. Operational Requirements and Equipment Maintainability Requirements



Ease of Inspection and Maintenance

Inspection and maintenance in operation (Figure 24) are facilitated by special features of design which enhance producibility, inspectability and testability. These features, covered from the production viewpoint in designing for producibility, aid the inspector or maintenance technician in conducting preventive and corrective maintenance (Figure 25) and in recognizing and diagnosing failures or weak areas and making repair as early and rapidly as possible. The viewpoint of design for operational maintenance ease is represented in Figure 26.

Modularity

The extension of simplicity goals to maintenance is encouragement for breaking the system into convenient modules for handling, troubleshooting, repairing and testing, then minimizing the types of modules. This becomes another feature for trade-off in the life-cycle cost analysis.

Built-in Test/Built in Test Equipment

Miniaturization and reliability improvement of circuitry that will check integrity of operating systems has made possible the "built-in" approach which alerts for failure, reduces repair response time, and can reduce operating cost and thus life-cycle costs. However, the addition of built-in parts can degrade reliability and maintainability through false alarms or induced system failures and will result in added space, weight and cost in the basic design. This is another example of system trade-off which must be made to optimize the life-cycle parameters.

Figure 25. Primary Subsets of Maintenance Activities

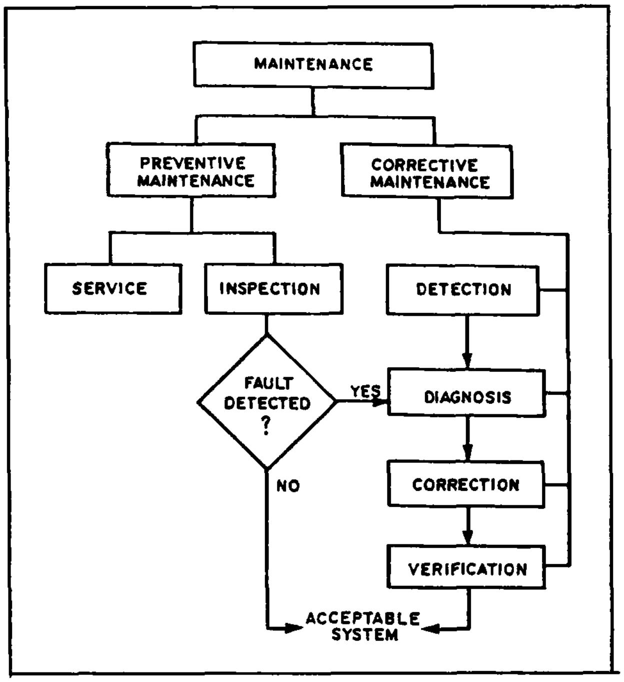


Figure 26. Ease of Maintenance Guidelines

Failure diagnosis, identification and replacement are facilitated by:

- Using modular design techniques
- Use of special built-in circuits for fault detection, error warning lights, etc.
- Designing for replacement at higher levels
- Using increased skill level technicians
- Increasing depth of penetration of localization features
- Utilizing test indications which are less time consuming and/or less difficult to interpret
- Designing for minimum diagnostic strategies
- Making accessible and obvious both the purpose of the test points and their relationship to the item tested
- Improving quality of technical manuals or maintenance aids
- Designing access for ease of entry
- Reducing number of access barriers
- Reducing need for isolation access by bringing test point, controls and displays out to accessible locations
- Reducing number of interconnections per replaceable item
- Using plug-in elements
- Reducing requirements for special tools.

Design Reviews

The management tool for ensuring proper consideration of reliability and maintainability issues is participation in the design review process as described in design management

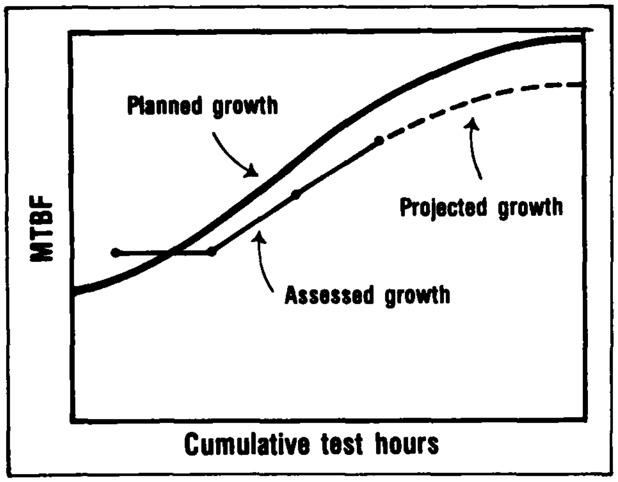
Test to Verify the Design

Testing the reliability and maintainability (R&M) picks up at designing and producing initial products and then operates in a test, analyze and fix parallelism to achieve the program goals. Both design qualification testing and R&M growth testing are involved. Design qualification testing measures the capability of the proposed design to meet established R&M goals. This is accomplished by comparing the design to a similar product with proven R&M values. After the basic design of a part, component or subsystem has been established/qualified, resources should be allocated to conduct R&M growth testing. Growth testing or Test Analyze and Fix (TAAF) consists of testing and then analyzing the results, correcting (fixing) the problem, and retesting (Figure 15). The purpose is to identify design, parts, and quality problems such that when fixed, the product will demonstrate through retest R&M growth and eventual design maturity. Figure 27 provides an example reliability growth format.

Sustain Reliability and Maintainability in Production and Service

The difference between inherent (or potential) R&M values and achieved values is shown graphically in Figure 28. The operation and maintenance of equipment in the field can induce these effects by stressing systems beyond predicted levels. Contributors to these overstresses include neglect, unfamiliarity, carelessness and mission

Figure 27. Example of a Reliability Growth Curve



constraints. And the real reliability can be obscured by scheduled and unscheduled maintenance actions. For example, in unscheduled maintenance, trouble-shooting might include installation of good parts to identify bad parts (put in a new part to see if that cures the problem). Even though the replacement does not correct the problem, the removed part may get written up as defective when it is in fact good but is not reinstalled. These parts then may be returned to a depot or discarded thus contributing to a report of lower than actual reliability of the component under discussion.

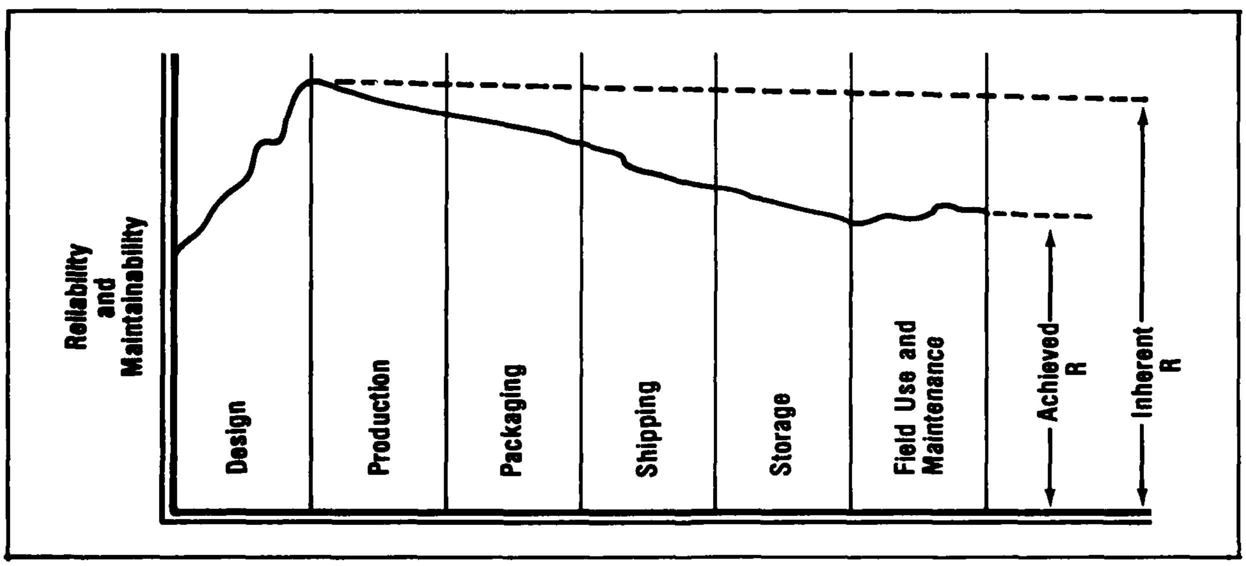
Scheduled maintenance can also induce defects in satisfactory assemblies: foreign objects left inside, fasteners improperly tightened, dirt introduced, improper part replacement, improper lubricants. Of course, a major effort is made in operations to reduce the effects of reliability degradation caused by maintenance. The point here is that the designer should consider the pitfalls of field maintenance and minimize the characteristics of the design which are susceptible to operationally induced reliability deterioration. And, equally important, reliability predictions and allocations should be made on realistic operational projections for degradation.

The key to minimizing and controlling R&M degradation is to identify defects introduced by production and service life. Two types of defects must be considered, quality defects and reliability defects. Quality defects are those that can be detected through the inspection and acceptance testing program. Reliability defects are those which require stress over a time period to detect. Some techniques for addressing reliability in production and in service are shown in Figures 29 and 30.

R&M Summary

Reliability and maintainability are dependent upon specific program activities with objectives as indicated in Figure 31 and performed as integral parts of the system acquisition process. A handy tool for establishing reliability goals and thresholds related

Figure 28. R&M During System Life



to operating time is provided in Figure 32. It is important that R&M be considered in the design process because identification of related problems in later stages of the life-cycle has an adverse cost leverage as generally shown in Figure 33.

Designing for Production

In the 1970s, some major DOD programs ran into high-production costs and significant delivery schedule problems, in large measure attributed to lack-of-design consideration for producibility, and poor planning for production. The phrase "transition to production" was coined to identify a quasi-program phase just before production. This terminology has left a wrong impression with many in the acquisition community that production considerations are taken seriously *only* when factory start-up is imminent; in response, the Defense Science Board looked at Solving the Risk Equation in Transitioning from Development to Production (Reference i). Templates for addressing that type of risk were developed and the importance of production consideration throughout the program was

Figure 29. Techniques for a Successful Program

Sustain reliability in production and service

- Process control
- Screening/acceptance tests
- Burn in

Sustain reliability in service

- Field data
- Corrective action
- Product improvement program
- Modifications

Figure 31. Objectives of R&M Activities

- Operational Effectiveness
- Ownership Cost Reduction
- Limit Manpower Needs
- Management Information
- Efficiency

Figure 30. Flow Chart of Reliability Program Based on Field Data

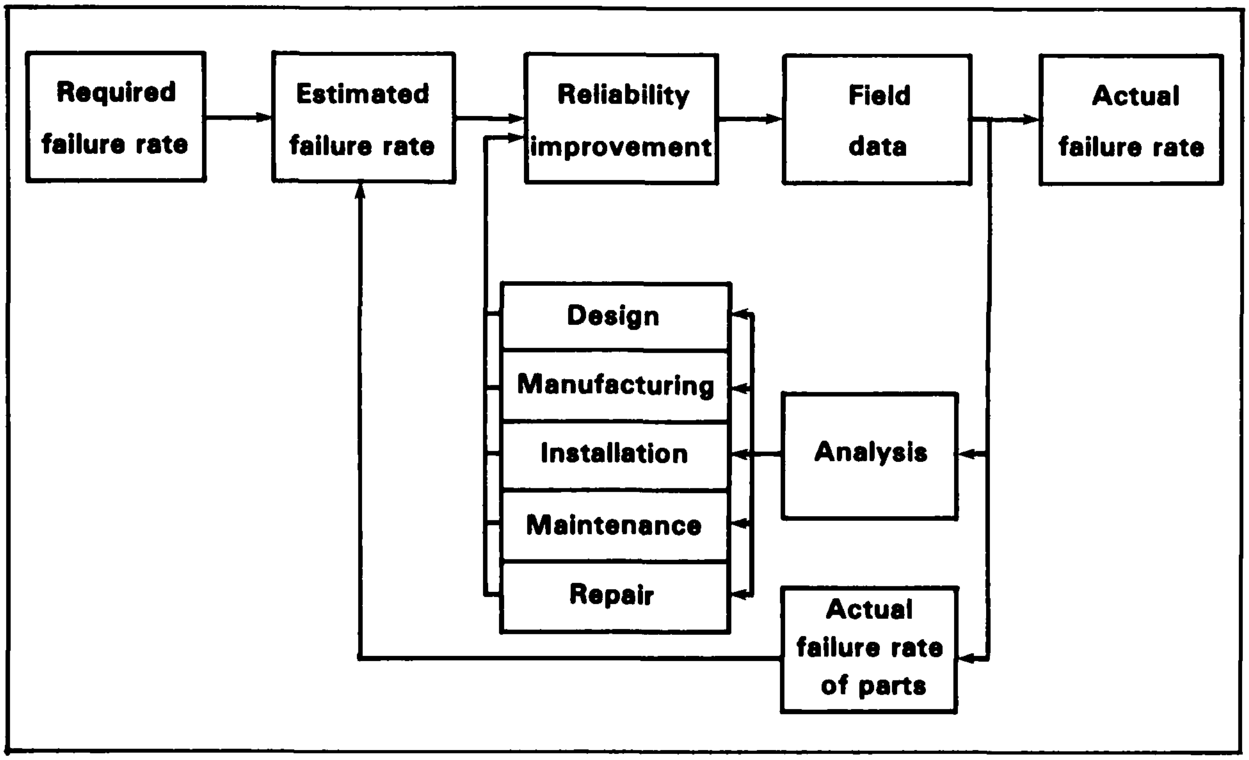
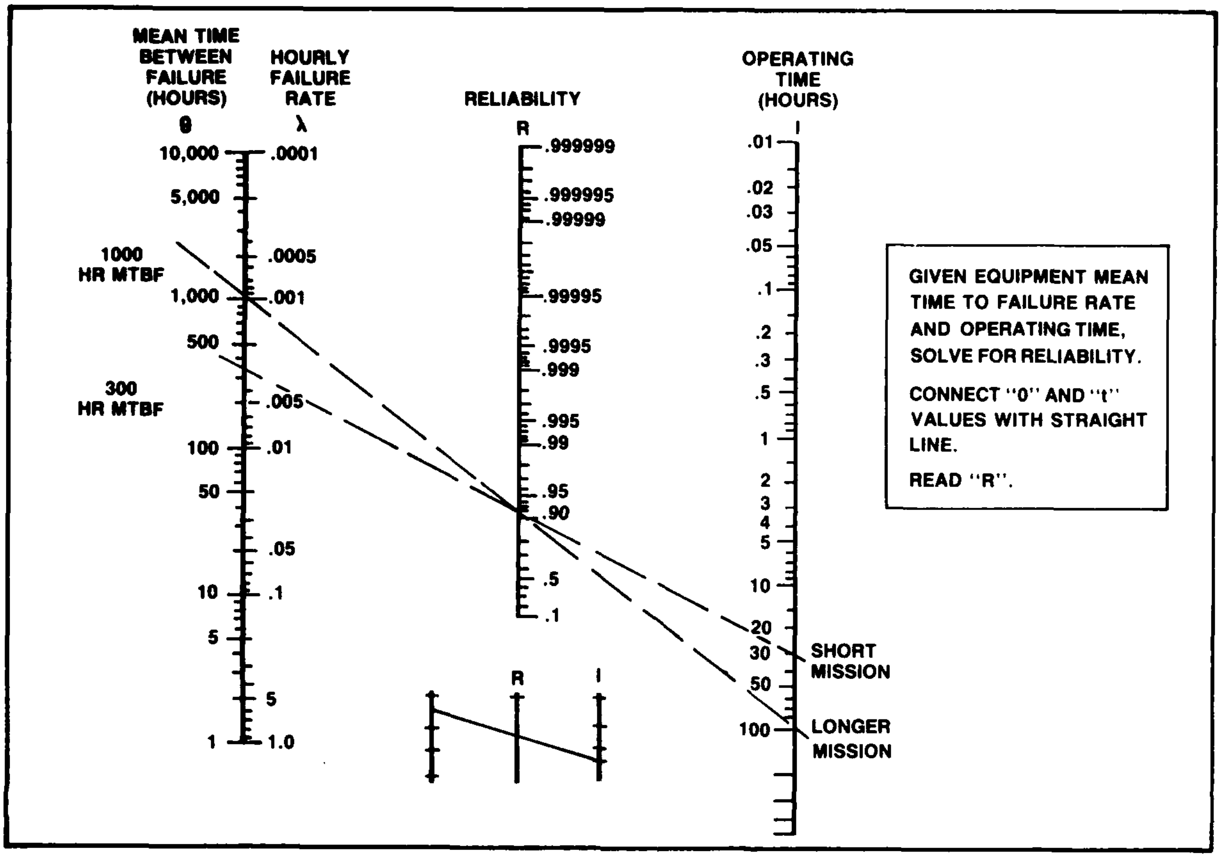


Figure 32. Setting Reliability Goals and Thresholds



clearly established. Designing for production (which starts in conceptual identification of solutions to needs) is the first step.

Definition (Reference j)

Producibility. The relative ease of producing an item or system. This is governed by the characteristics and features of a design that enable economical fabrication, assembly, inspection, and testing using available production techniques.

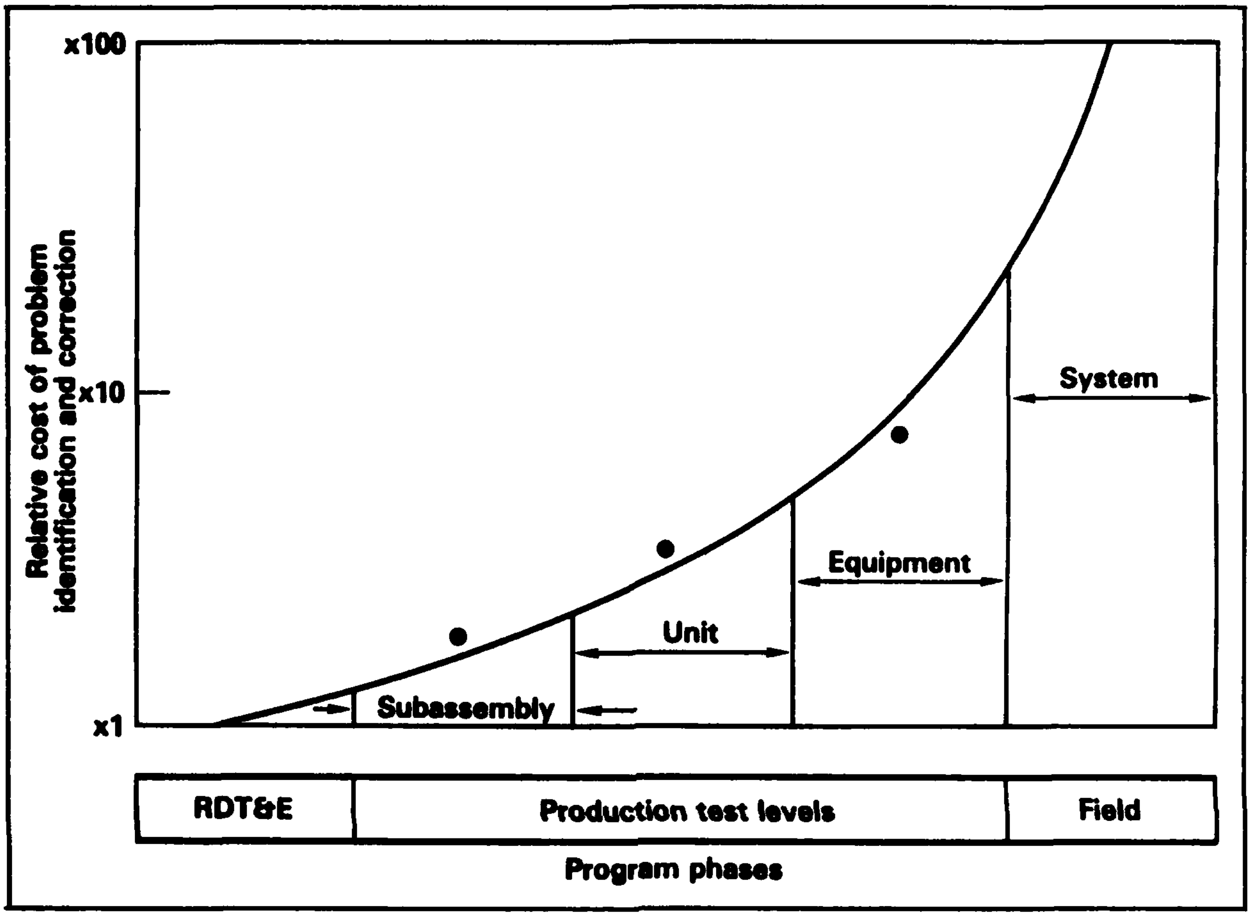
"...ease of producing...." recognizes that a performance indicator of a production process is the "ease" of operation which can be observed; e.g., grinding sparks fly as excess material is removed, people weld in uncomfortable positions or complicated fixtures are required to properly position parts for joining. This issue is addressed by coupling the design and manufacturing process and then continuing to improve the quality of both.

"...governed by...design" recognizes that the design does influence ease of producing. The designer must address questions like; does the design/manufacturing tolerance in detail parts manufacture permit assembly ease? Does the design consider human factors to facilitate assembly? This issue is also addressed by coupling the design and manufacturing process and then continuing to improve the quality of both which leads to another interesting phrase in the producibility definition.

"...inspection and testing...." recognizes that the manufactured product must be inspectable and testable. Why? To be able to assure that performance meets requirements, certainly. But it is important to look at more than the quality of the product, equally important is the quality of the manufacturing process. Failure analysis should address both quality of design and quality of manufacturing process then may extend to the realism of the requirement and address what is really "fit for use."

"...using available technology...." recognizes a major risk area, the assurance that selected techniques

Figure 33. Relative Costs of Problem Correction versus Program Phase



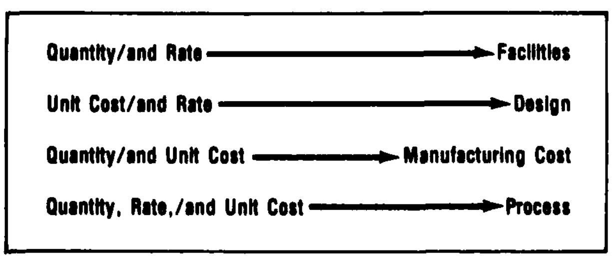
will be successful in manufacturing the specific product under development. The span of consideration is not a narrow window as the system transitions to production. During the conceptual cycle it is necessary to identify and institute the necessary development programs to assure that required manufacturing technology is available when needed.

Importance of Quantity, Rate and Unit Cost Goals in Design

Instability in acquisition goals is a major problem for product definition. When quantity, rate and unit cost are identified, the design is coupled with the manufacturing process and the optimum is largely "locked in" for the given parameters. The related logic is illustrated in Figure 34 (read the arrows as "largely influence" as opposed to exact relationship).

Establishing quantity and rate will drive capacity decisions such as number of plants or production lines required and configuration (i.e., job shop, station capability, ordered stations, integrated station flow, automation) of the facilities. As quantity and rate increase, business and management considerations drive the facility configuration from a job shop toward high technology automation. Ob-

Figure 34. Acquisition Strategy Impact/on Manufacturing



viously, a major trade-off is made between labor and capital investment. A current approach to adaptation for changes as well as achieving low and high values of quantity and rate is the development of flexible machining centers wherein computerized and automated techniques minimize set-up time and cost. As computer aids become increasingly economical, the installation and conversion to flexible equipment will require less capital and the designer will have more latitude to involve what are now generally considered high quantity/rate low-cost per unit manufacturing processes. However, in the remainder of this decade establishing quantity and rate of production will have a significant impact on identifying *the* optimum facility.

Establishing unit cost and rate will affect design decisions such as types of casting or welding to be employed. Design and manufacturing process linkage is tight for these examples not only because the design must contain configuration features (e.g., draft angle in castings, joint geometry in welding) peculiar to the selected process but also because resulting material physical properties (and thus size and weight) are sensitive to the selected detail process. To minimize impact of change, the designer must consider the future and proportion to allow accommodation of the widest practical, probable variation in optimum manufacturing process.

Establishing quantity and unit cost will affect optimum manufacturing cost (defined here as cost to support the manufacturing effort; e.g., tools, planning, process description, training). Based on givens, decisions will be made such as whether to develop "hard tools," a detailed process and training for the work force or minimum description and tools for skilled workers in a "job shop." A current approach to flexibility in this consideration is the application of computer aids in developing tools, plans, and documentation and the establishment of a flexible, skilled work force with appropriate labor relations to allow job blending and mobility.

The key point is that **establishing quantity, rate and unit cost** will largely influence (drive) the optimum manufacturing process which likewise depends upon facilities, design, and manufacturing cost. Realistically, during the program life-cycle changes in procurement strategy do occur and the design should be developed to provide flexibility for the most effective manufacturing process. It is important that the program office develop economic relationships for the optimum matching of design with acquisition strategy and be prepared to track and brief the economic impacts of variations in quantity, rate and unit cost goals.

Figure 35. Some Consequences of Inadequate Manufacturing Involvement During Development

- **Low-process yields ---- High scrap/rework rates**
- **Restricted data rights and non-standard call-outs ---- Limited availability and hi costs of parts/components**
- **Time-consuming adjustments/calibrations ---- Prolonged manufacturing cycles and increased quantities of instrumented equipment**
- **Difficult-to-machine shapes, materials, tolerances, finishes ---- Unique machining capabilities**
- **Difficult assembly requirements/sequences ---- Frustrate use of automatic assembly techniques**
- **Unique production skill ---- Difficult labor recruitment/training**
- **Overly stringent or ambiguous acceptability criteria ---- High MRB activity**
- **Optimistic production schedules ---- Schedule slippages**

Coupling the design and manufacturing process is achieved by providing the environment for design engineers and manufacturing engineers to work together. This team addresses issues such as those listed in Figure 35.

Low Process Yields

A significant measure of a manufacturing process is the percentage of item starts that complee the process (e.g., 100 items are started but only 90 complete the process; the yield is 90 percent). Scrap, repair and rework impact the process efficiency. The term "hidden factory" has been coined to describe the out-of-station activity (repair, rework) established by U.S. producers to keep the production line going. The hidden operation of the factory many times does not conduct failure analysis to determine cause of the problem and then corrective action. But the most insidious effect is the usual lack of cost accounting which masks the real (increased) cost of (poor) quality. The hidden factory is under attack as counter-productive based on the empirical evidence of Japanese success achieved through meticulous dedication to perfection in design and manufacturing process. The watchwords are "fix the process" (which may include fix the design) and "quality (including quality of design) yields productivity."

Restricted Data Rights and Non-Standard Call Outs

These issues are listed together because the result for DOD is similar, sole source or at least reduced competition. The first issue (restricted data rights) arises through incorporating a manufacturing process developed by the contractor which is claimed as proprietary. There may be a variety of reasons why this is necessary and a complete discussion of the issue is beyond this scope. If practical, the condition should be eliminated. The fundamental point is that the condition should be identified through requirements for identification under the contract and continual vigilance in the design review process. Then effective action can be taken to eliminate the problem by purchasing data rights or requiring design change or managing the problem by buying out life-cycle support requirements or planning and budgeting for restricted source. In any event, the problem should be exposed and plans for the solution developed with cognizance of acquisition executives.

Non-standard call-outs here refer to components which have not been identified and selected from the standard parts list developed for the program or which have not been altered economically to be standard. The point is that a standard parts list should be developed for design use and then the team should effectively apply standards. This activity can be managed by the government through requiring program office non-standard parts approval.

Time-Consuming Adjustments/Calibrations

This issue relates to both the product design and the manufacturing process. A design-related example is lack of part tolerance control or very tight assembly tolerances (or both) which then requires selection of components for assembly (e.g., detail parts with measurements to obtain a specific fit in a mechanical device; specific electrical value of a component to achieve a required circuit parameter). The manufacturing side of the issue relates to the techniques for verifying the process. Calibration and adjustment of test equipment are typically very important and very costly for DOD products. Therefore, it is important to address the need and productive techniques available for test and inspection. The point is that this discipline does not add value to the product; therefore, design adaption to minimize labor in process verification and application of modern test and inspection technology can improve productivity significantly.

Difficult-to-Machine Shapes, Materials, Tolerances, Finishes

A major contribution of manufacturing engineering to the early design process should be description of the available manufacturing processes and capabilities. The designer should then define a product which can be produced with these processes or identify shortfalls for economic analysis to determine appropriate action for process development or design change.

Difficult Assembly Requirements/Sequences

The assembly activity is usually labor intensive and difficult to estimate in early stages of development.

Figure 36. Distractors to Design for Producibility

- **PMO FOCUS**
  - **Short-term forced by environment**
  - **Long-term (not required)**
- **CONTRACT REQUIREMENTS**
  - **Cost**
  - **Schedule**
  - **Performance**
- **LAWS**
  - **OSHA and EPA**

Therefore, producibility review involving design and manufacturing is particularly important for assembly requirements. "If you're going to use robots, design for robots" makes some sense. Manufacturing engineers looking at the design from an assembly point of view can bring considerable insight to the process (e.g., placement of fasteners to facilitate manual or automatic installation, clearances to permit use of standard tools and test equipment).

Unique Production Skill

If the "optimized process" requires a skill not resident with the producer, a whole new set of problems arise—recruitment, training, and inserting the skill in the labor relations scheme. Producibility review should identify this type of problem. Then change the process to eliminate the need or plan to acquire it.

Figure 37. Motivation to Design for Producibility

- **The product is needed, fulfills requirement**
- **Evolution is expensive**
- **Objective of design phase is manufacturing**
- **Producibility enhances program longevity**

Key point
Motivation should be to design for producibility

Overly Stringent or Ambitious Acceptability Criteria

Everyone involved in the production—designer, product assurer, manufacturing processor, gage maker, tester—wants a "safety margin." If each one takes 10 percent extra to assure meeting the requirement, it is tightened well over 50 percent. This type of well-intentioned thinking contributes to rejecting parts and assemblies that are acceptable quality. This aggravates the hidden factory phenomena described above and as a minimum increases inspection and/or test rejections handled by material review board (MRB) action which then finds the part or assembly "acceptable as is." Before this occurs, the design/manufacturing review process should expose the problem for correction. (If it occurs in production, the MRB manufacturing representative should rightfully ask: "Why don't you change the requirement?")

Optimistic Production Schedules

Commitments to production schedules in support of the fielding plan are typically made before the detailed design is anywhere near completion. Since there is pressure to tell buyers what they want to hear, production planners must work closely with designers in early development to understand and justify production process requirements and schedule allocations in a better way. Simple lack of execution at the component level can reflect serially through system fabrication, having drastic schedule and cost implications. Strategic implications can be critical; e.g., the world was waiting for Pershing II to be on time.

Producibility Distractions

Though the design for producibility techniques are relatively straightforward and simply stated, there are serious distractors (Figure 36) for both the government and the contractor. Realistically, there never seems to be enough resources to do the job. Where are these skilled production analysts that can help? And if they can be found, where is the money to support them? The pressure to define something that works and show performance overwhelms long-term reasoning. What is long term? With 3-4 year duty rotation, fruits of development may never be seen in production. The response, of course, is that producibility engineering and planning (PEP) is really not an optional activity;

it will be conducted early and effectively or later in piecemeal fashion with great agony and expense. The DOD program office and the contractor must identify the need, establish the requirements to accomplish the goals, and diligently defend the acquired resources to assure that the required tasks are accomplished.

Given a development contract with defined cost, schedule and performance requirements, there are watchbirds and alligators everywhere. If there isn't ample management reserve to cover hard-to-predict ("unknown unknowns") shortfalls in these areas, temptation to allocate from producibility studies will be great. Who will say: Stop, stretch schedule, send more money now and you'll get it back later in improved producibility? The program office must believe in design for producibility and supply the incentives and resources to see that it occurs. One technique is a formal Producibility Engineering and Planning Program (Reference k). The alternative, a less formal approach, should encompass the principles presented in References (i) and (k) as generally outlined in this section.

Influences upon design and manufacturing engineering may come from external sources. Examples are regulations from the occupational safety and health administration (OSHA) and the environmental protection agency (EPA). New regulations or alerts requiring immediate attention may arise in the middle of a program. An OSHA example might be the identification of a carcinegenous material used in the program and the resulting requirement to protect humans from the effects, an endeavor which could obviously seriously effect cost, schedule and performance. Examples of EPA concern might be environmental impact from a planned new manufacturing facility and disposal of toxic manufacturing process materials. These issues are relatively common and can have serious program overtones. The point is that the program office must have a source for continual vigilance in these areas. Typically, major contractors have functions responsible for these issues and track them as a matter of doing business and in response to contracts which require conformance to OSHA and EPA regulations. The services also review drawings for regulation conformance but too late to have the desired early effect on producibility design.

Motivation

Many in the DOD acquisition community, who point accusing fingers saying contractors are interested only in maximum sales and profits, assume there is no incentive for low-production costs. To examine this accusation, consider the logic of Figure 37. Presumably, the product is needed; it fulfills a requirement. We are a needs-driven society. This is the fabric of our society—a concept most of us have embraced. Evolution is expensive (read evolution as iteration if it is clearer, the concept of "here's an approach, can you build it; no, okay, I'll change it; how's this?"). Design changes to improve producibility after production start require alteration of configuration controlled drawings and can require changes in the support plans and equipment, spares, and other logistic resources. It is recognized that late changes for producibility will be resisted and may, in fact, be uneconomical due to early fixed commitments for operation. Fortunately, the designer should recognize that the objective of the design phase is manufacturing.

A simple model designers use is shown on Figure 38. First, the product design (which meets performance requirements) and manufacturing process

Figure 38. Design for Producibility Model

- Define design(s)
  - Product (PEP)
  - Process (IPF)
- Breakdown to small-cost elements
  - Hardware
  - Software
  - Support
- Attack leverage elements (PARETO)
  - Cost
  - Mission essential
  - Safety of operation
  - New technology
  - Long lead materials
- Criteria is DTUPC/LCC allocated to WBS element

are coupled through consultation with functional experts. The formal programs which establish goals and fund actions for producibility include producibility engineering and planning (PEP) and initial production facilities (IPF). Using a work breakdown structure, the elements of the design are defined and an associated cost for each estimated. Then the designer attacks the leverage elements, that is, the high value items, particularly those that appear costly for their function.

The implication of PARETO is that if the items are placed in order of cost from highest to lowest, then the top 20 percent will cover 80 percent of the total cost. Focus on the top 20 percent in order of cost is a common technique for considering leverage but there are other important considerations as indicated in Figure 38 and the job is not complete until all items are considered in the proper system perspective. For this type of analysis, there is a distinction to be made regarding design for a type of cost, design to unit production cost (DTUPC) and design to life-cycle cost (DTLCC). The minimum unit production cost *estimate* may not always yield the minimum life-cycle cost *estimate*. Therefore, the designer will have to receive guidance regarding the priority.

Figure 39. Program for Producibility

- Establish goals
  - Total quantity
  - Rate
  - UPC
  - LCC
- Select contract(s) plan
  - Cost
  - Incentive(s)
  - Fixed
- Establish producibility plan
  - Concept formulation - UPC/LCC analysis
  - ED - Analysis/proof as possible
  - FSD - Analysis, rate proof as possible, PEP, PRR
  - LRIP - Analysis, PEP, rate proof
- Monitor contractor

Returning to the logic of motivation outlined in Figure 37, the contractor marketing/sales functions should recognize that producibility enhances affordability which, in turn, enhances program longevity. What better reasons to motivate the key players? The point is that contractors do have motivation to design for producibility. It is generally the instability of requirements and lack of program office focus on producibility that stifles the inherent motivation. The program office must provide a stable acquisition strategy and execute an effective program which provides necessary resources to design for producibility. A general outline for a producibility program is shown on Figure 39; details can be found in References (i), (k) and (l).

Design for Producibility Summary

The acquisition strategy which defines quantity, rate and unit cost goals largely influences the optimum production process. Therefore, the program office should provide a stable acquisition strategy and then enhance inherent motivation for producibility. Specifically, the product design and production process should be coupled through effective design and manufacturing engineer consultation on issues such as those shown on Figure 35. The process is managed by establishing a program responsive to References (i), (k) and (l) which will include a series of design reviews to confirm that producibility issues have been exposed and resolved.

Designing for Special Systems Requirements

The design is influenced by many requirements special to the specific system under development. A representative list of specialties includes:

* System Safety
* Human Engineering
* Electromagnetic Compatibility (EMC) and Interference (EMI)
* Contamination and Corrosion Control
* Survivability and Vulnerability
* Hardware/Software Integration
* Operation and Support

System Safety

This is the engineering process which identifies, evaluates and controls hazards throughout the life-cycle of the system. It includes anything that could

cause or prevent accidents (hardware, software, people, environment). Tasks include hazard analyses during design, development and test, surveys, investigations, and preparation of accident plans.

Obviously, this activity is extremely important for the health and well-being of users and the community at large. But the economic implications are also important as indicated in Figure 40.

Safety engineering, which integrates design for minimum hazards, is detailed in Figure 41 (recall the relationship to failure modes, effects and criticality analysis covered in relation to Figure 18). The hazards are defined through a series of analyses listed in Figure 42. Residual risks are determined and design goals are established in a manner illustrated in Figure 43. When a design-related safety problem is identified, the scientific method/system engineering will require definition of alternatives that will control the condition. Priority ranking used to select one of the design alternatives can be established by the technique illustrated in Figure 44.

Human Engineering (Reference m)

Human engineering specialists address the people-equipment interface. They apply principles of human capability (to reach, lift, see, communicate, comprehend, and act) to the functions and circumstances required. They are another team member in the design process whose goal is to optimize the system. They first allocate systems to personnel, equipment, software, or facilities. The level of involvement and criticality of personnel tasks are identified. Human factors engineers then use task analysis and time-line studies to determine if human capabilities will be exceeded. They prepare models and mockups to evaluate alternative designs or concepts and for dynamic simulation of critical human performance. Human engineering specialists work with design, system safety, maintainability, testing, training, production, subcontractors, deployment, logistic support, and operations personnel. Focusing program attention on protection of personnel from hazardous environmental conditions is their most important activity.

Figure 40. Two Safety Approaches

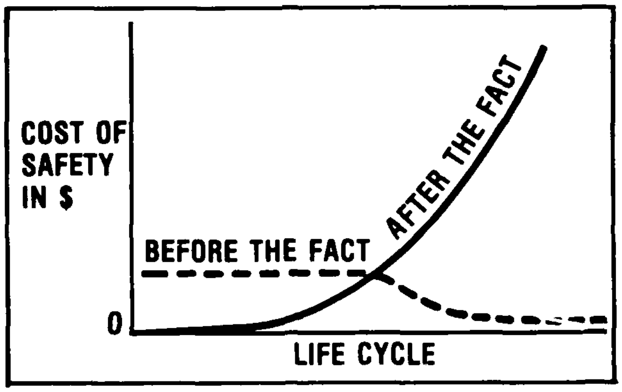


Figure 41. System Safety Engineering and Precedence

- Identify Hazards in the System
- Define Hazards in terms of Severity and Probability
- Design for Minimum Hazard, within the Constraints of Operational Effectiveness, Time and Cost
- Control Remaining Hazards, with Safety Devices, Warning Systems, and Operating Procedures
- Understand and Accept Residual Risks

Figure 42. Hazard Analysis

PHA - Preliminary Harzard Analysis

SSHA - Subsystem Harzard Analysis

- Fault-Hazard Analysis
- Fault-Tree Analysis
- Sneak-Circuit Analysis

SHA - System-Hazard Analysis

O&SHA - Operating and Support-Hazard Analysis

Figure 43. Risk Design Goals

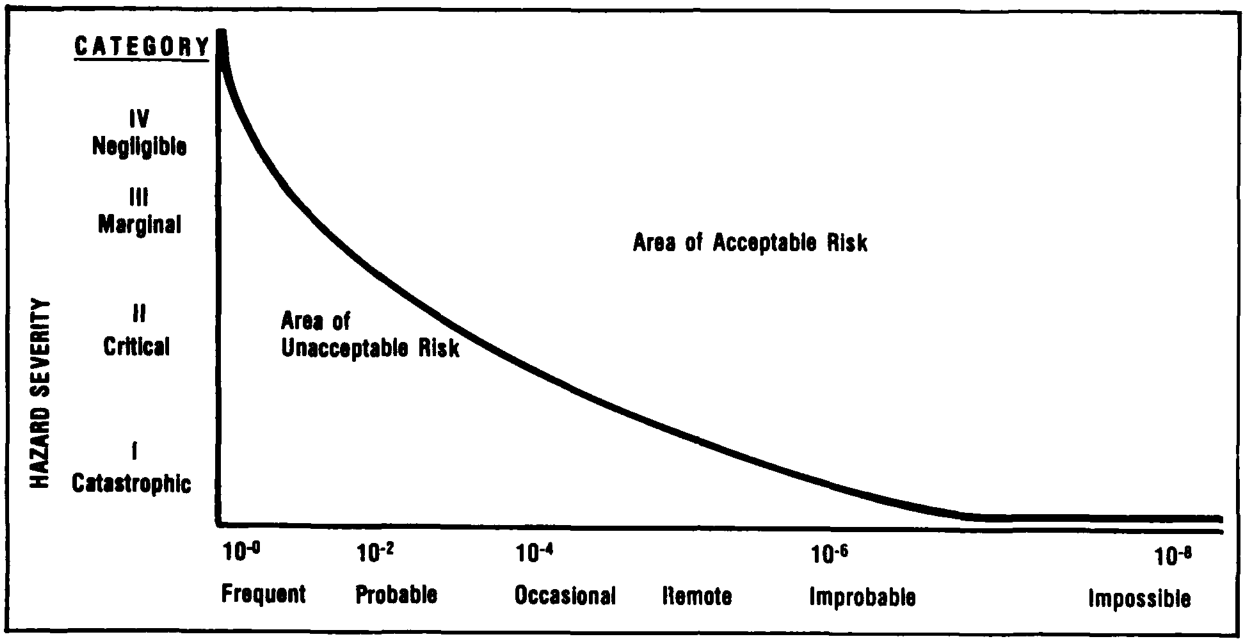


Figure 44. Sample System Safety Ranking for Implementation

SEVERITY	LIKELIHOOD	COST IMPACT	VALUE
A (High)	J (High)	P (Low)	4
B	K	Q	3
C	L	R	2
D (Low)	M (Low)	S (High)	1

Highest Ranking = 12 (AJP) Lowest Ranking = 3 (DMS)

Where numerical values are equal, rank by

1. Severity
2. Likelihood
3. Cost Impact

Example: Numerical value of 6, ranking would be BLS, CLR, DLQ

EMC/EMI (Reference n)

Unintentional electromagnetic radiation can cause unacceptable degradation (e.g., interference to electronic equipment within range or initiation of electroexplosive devices). Electromagnetic compatibility is achieved by eliminating or controlling unintentional radiation to an acceptable level or by shielding equipment from its effects. Protection from lightning and static discharges are included in this discipline.

EMC/EMI specialists address electromagnetic sources of radiation within the system such as: motors, generators, power sources, signal and power wiring, transformers, and relays. They develop design criteria to minimize potential problems related to items such as radiation-shielding, bonding, lead lengths, wire routing, component placement, and decoupling. It is usually necessary to perform a detailed analysis of the electrical power system to determine power bus characteristics and dynamic impedance and to evaluate any undesirable steady state or transient effects. Development and qualification tests include EMC/EMI tests to measure unintended radiation and its effects.

Contamination and Corrosion Control (Reference o)

Several types of manufacturing require contamination control. Semiconductors, microelectronics, and precision bearings are examples that require atmospheric control of airborne particles and control of surface contaminants. Equipment applications and environments may require moisture, fungus, and corrosion prevention techniques in design, manufacturing and surface protection.

The advent of space systems and the Space Transportation System has resulted in system application requirements for contamination controls which far exceed other system applications in complexity and mission critical consequences. Ultracleanliness is important but, in addition, space-induced and operationally-induced contaminants are critical to instruments and optics. For example, outgassing of materials, volatile condensable materials, and the output of upper stage propulsion devices are some of the contaminants which must be controlled.

Military equipment operates under the most difficult environments imaginable. Extremes of temperature, humidity, sand, dust, salt spray, and rain all tend to debilitate equipment rapidly. Without proper resistance or protection, much equipment would fail to function when required. Protection must be provided by the proper specification of materials, covers and seals, packaging, heating and cooling devices, or other design features which permit extended storage and operation throughout the range of operational environments. Once a qualification unit has been built, it must be subjected to tests which encompass the full range of environmental requirements, plus a margin of safety or derated performance criteria (as covered in Figure 6).

Figure 45. Survivability

$$P_S = 1 - (\overbrace{P_D \times P_{H/D}}^{\text{SUSCEPTIBILITY}} \times \overbrace{P_{K/H}}^{\text{VULNERABILITY}})$$

$$\text{Probability of survival} = 1 - \left(\text{Probability of being detected} \times \text{Probability of being hit if detected} \times \text{Probability of being killed if hit}\right)$$

THE CAPABILITY OF A WEAPONS SYSTEM TO WITHSTAND MAN-MADE HOSTILE ENVIRONMENT WITHOUT SUFFERING AN ABORTIVE IMPAIRMENT OF ITS ABILITY TO ACCOMPLISH ITS DESIGNATED MISSION

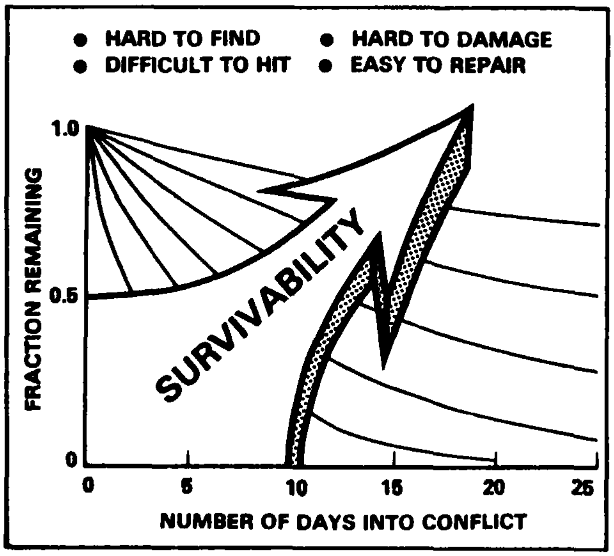
Survivability/Vulnerability

Military systems are vulnerable to the natural environment of ground or space and to hostile threats from ground forces, sea forces, air forces, and antisatellite weapons or nuclear detonations. Specialists in survivability/vulnerability engineering analyze and evaluate these natural and induced threats in the concept exploration phase to determine the design approach and methods required to meet survivability requirements which are then included in the system specification. Figure 45 shows the analytical approach for evaluating the manmade hostile environment and Figure 46 illustrates the design approach to countering the threat—hard to find, difficult to hit, hard to damage, easy to repair—which includes considerations for detection, evasion, and damage as outlined in Figure 47.

Specialists analyze the vulnerability of the system in terms of the capability of parts and materials, protective measures, system architecture, functions, and controls. Risks and alternatives are assessed in trade-off studies which lead to design criteria and decisions to reduce vulnerability and improve survivability. A list of survivability and vulnerability trade-offs is included in Figure 48.

Nuclear survivability and vulnerability are special concerns for many systems. The threat is generally depicted in Figure 49. Design techniques for addressing the strategic and tactical threats are beyond the scope of this document.

Figure 46. Design Approach



Hardware/Software Integration (Reference p)

The primary instrument of hardware/software integration is the hardware/software Interface Control Document (ICD). The ICD is required to specify the functional interface between the computer program product and any equipment hardware with which it must operate. It is often true that the supplier documentation for standard computer peripherals and terminals is adequate for this purpose. Conversely, it has been found that performance specifications governing the design of new equipment is not satisfactory for use as a functional ICD. The purpose of an ICD is to communicate interface requirements to programmers on terms that the programmers readily and accurately understand and to require equipment designers to consider the impact of their design on computer programs.

The ICD provides an exact definition of every interface, by medium and by function, including input/output control codes, data format, polarity, range, units, bit weighting, frequency, minimum and maximum timing constraints, sequence or ordering constraints, legal/illegal values, and accuracy, resolution, and significance. Existing documentation may be referenced to amplify explanations of the effect of input/output operations on external equipment. Testing to validate the interface designs is also required.

Figure 47. Survivability/Vulnerability

- DETECTION
  - Sound Level
  - Electromagnetic Radiation
  - Infra Red Radiation
  - Tactics
  - Terrain
  - Optical
  - Radar Cross Section
  - Countermeasures
- EVASION
  - Size
  - Velocity
  - Acceleratin
  - Configuration
- DAMAGE
  - Armor
  - Vulnerable/Lethal Area
  - Nuclear Hardness
  - Chemical
  - Redundance
  - Separation
  - Fire Suppression
  - Damage Tolerance
  - Fail Safe Response

Figure 48. S/V Tradeoffs

- SIZE/SPACE
- WEIGHT
- FUEL
- MOBILITY/AGILITY
- RANGE
- PAYLOAD
- COST

Operation and Support

The majority of life-cycle cost is spent on operation and support. Therefore, issues related to personnel and training, support equipment, and supply should impact the design early and effectively. To do this, "design to" requirements relating the logistic needs and constraints in the system must be established early. The resulting design will affect (Reference q):

* **Using personnel** in terms of quantity, type, and required training
* **Support equipment** in terms of quantity and level of technology (which effects equipment cost, operating cost, and training cost)
* **Supply** (which effects quantity of spares, the system to handle them and the system to use them).

Designing for Cost Objectives

Design-to-cost (DTC) often gets bogged down in definitions and cost accounting. Capriciousness is encountered such as showing conformance to goals by juggling books while ignoring the principles. The thrust here is to cover what the designer does

Figure 49. Nuclear Threat

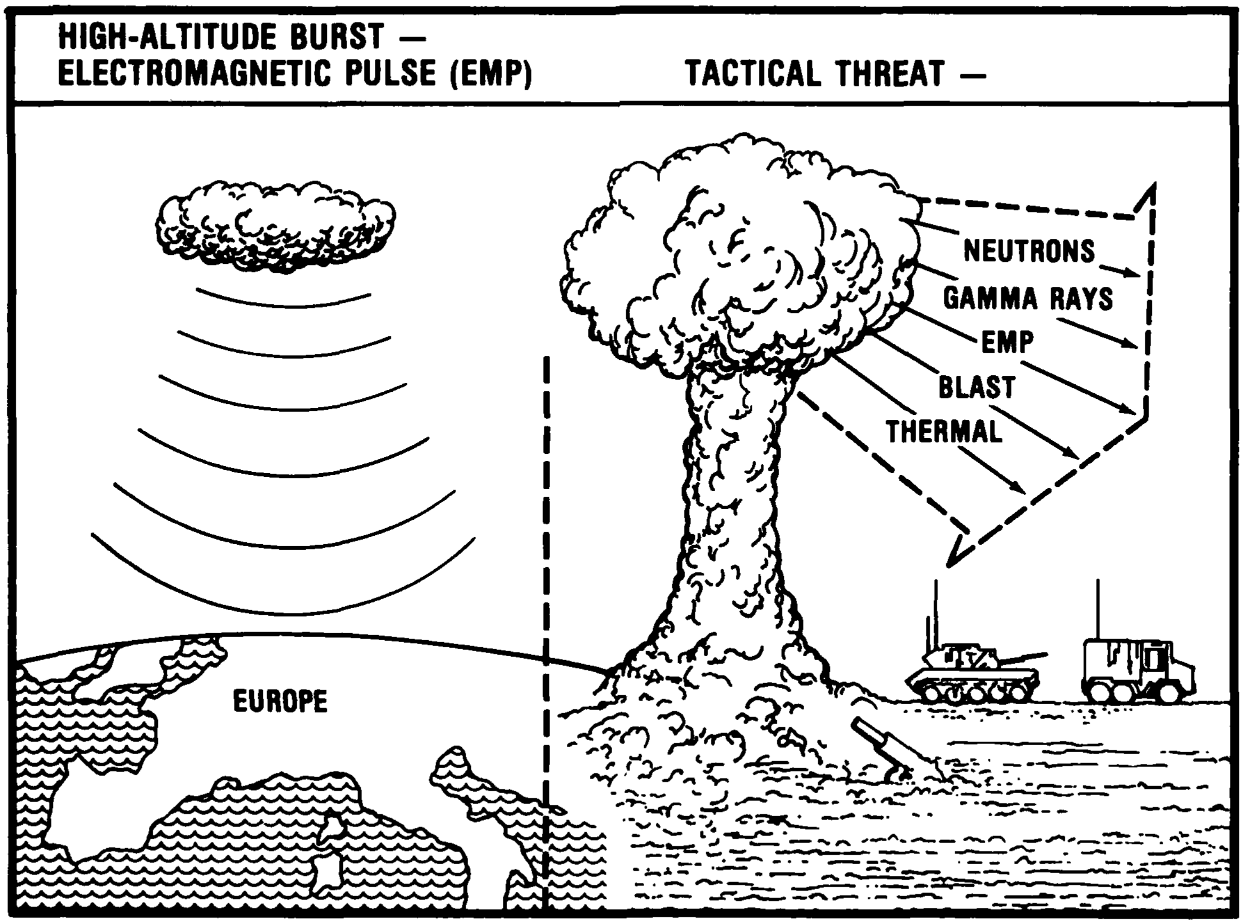
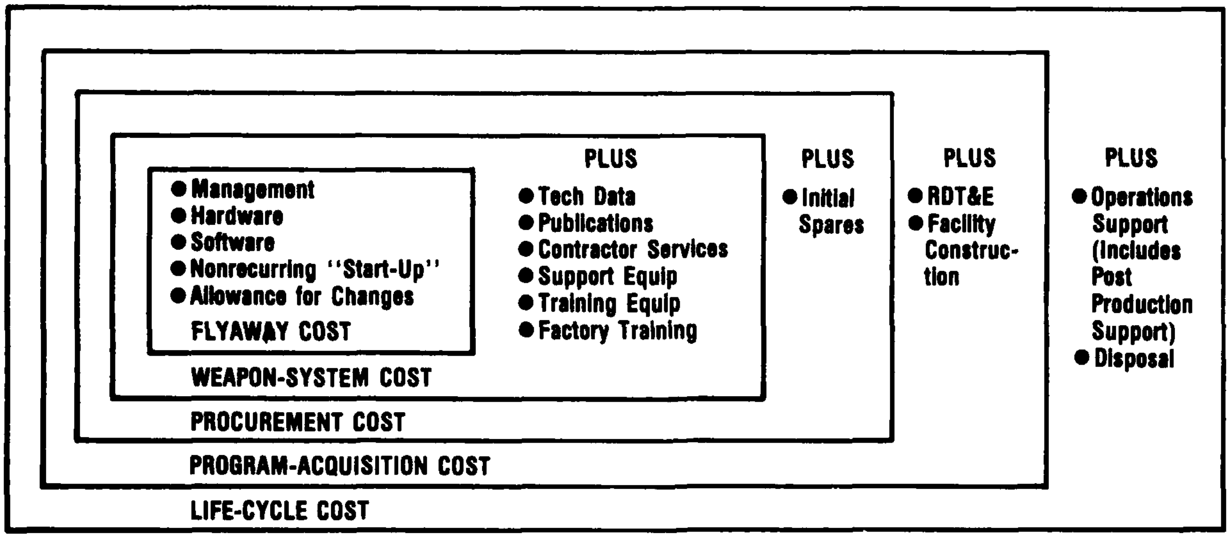


Figure 50. Life-Cycle Cost Composition



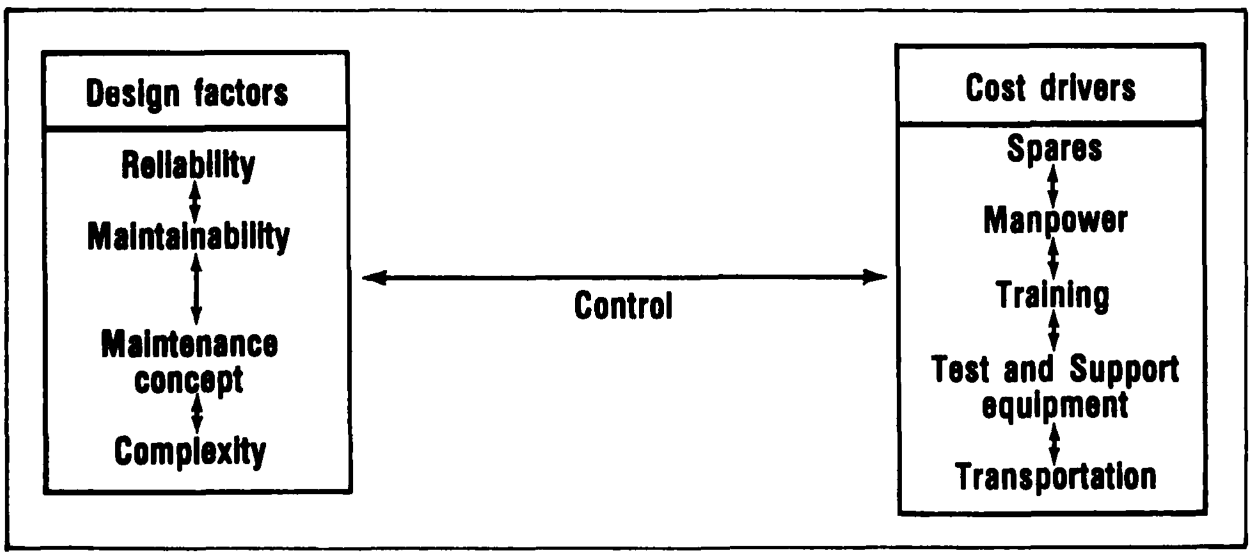
(review Figure 38) not what the accountants do, and the following is offered for the clarity of purpose.

DOD clearly provides guidance that life-cycle cost considerations are important in early design phases and should be used to develop effective systems.

(Reference r) During each acquisition phase, engineers and managers shall provide prompt feedback on the current status of DTC forecasts and timely estimates of the costs of new or alternative designs or other economical solutions. Engineers and managers shall achieve a proper balance in DTC emphasis between acquisition and operation and support (O&S) costs.

(Reference s) Tracking of DTC status (whether in terms of dollars or other measurable factors) shall continue until DTC parameters are met. For production, this could occur when actual costs for the specified DTC quantities have been reported and compared to stated DTC parameters. For O&S, tracking shall continue until the level of achievement can be determined in circumstances that approximate a mature operating environment.

Figure 51. Design Linkage



When goals are set, they should be based on the boundaries identified in Figure 50 which shows life-cycle cost composition. This will be effective if a single authority (designer, contractor, program office, service executive) will assume responsibility for establishing specific DTC goals and tracking impact of proposed designs through the life-cycle cost composition. Figure 51 shows design linkage with operation and support cost drivers.

This leads to equal consideration for cost along with performance, supportability and schedule. In turn, design-to-cost becomes part of the system engineering process (Figure 52). Specifically, when goals are set they are based on designer's concepts, and estimates to support the goals are developed using the best tools available. As the design is refined, more details become available and the estimate can be refined. Figure 53 is an example format for

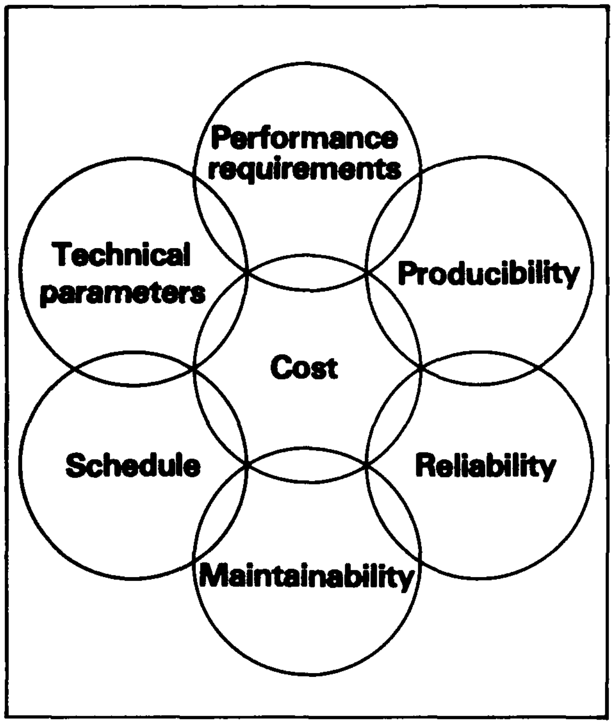
Figure 52. Implementating Design-to-Cost

- Systems Engineering Process
- Logistics Support Analysis (LSA)
- Producibility Engineering and Planning (PEP)
- Work Breakdown Structure (WBS)
- Cost Estimating and Models
- Configuration Management
- Contracting and Incentives
- Management and Tracking

Figure 53. Subsystem Managers are Responsible for Key DTC Parameters

			Subsystem Manager	Unit Production Cost	Reliability	Maintainability	Weight
1000		Air vehicle					
1100		Airframe					
1110		Basic structure					
	.01	Forward fuselage					
	.02	Center fuselage					
	.03	AFT fuselage					
	.04	Wing					
	.05	Empennage					
	.06	Landing gear					
1120		Secondary power					
1130		Hydraulic					
1140		Flight control		A L L	O C A T I	O N S	
1150		Electrical					
1160		Environmental control					
1170		Crew station					
1180		Fuel system					
1190		Airframe integration					
1206		Engine integration					
1300		Avionics					
1310		Communication and identification					
1320		Navigation and flight aids					
	.01	INS					
1330		Flight control system					
1340		Airborne weapons control					
	.01	Radar					
1360		Control and display					
1360		Electronic warfare					
1370		Mission computer					
1400		Armament weapons delivery					

Figure 54. The Name of the Game



breaking down a design and allocating difficult, but achievable, goals. The designer responds to this type of system engineering.

Managing the Design

Thus far, design considerations have been covered as separate topics. In the final analysis designing is a big trade-off game with cost at the center (Figure 54). It must be conducted by a capable source familiar with, and responsive to, the DOD review process.

Source Selection. Obviously, the search is for the source that has the tools and talent for the job, at the right price. Evaluators should address design tools in terms of productive capacity to do the job, ability to generate alternatives and support trade-offs, and compatibility of data output with system requirements. The designers (talent) must be adept at using the tools and experienced in the system design process. For the foreseeable future, design rooms will exhibit considerable turmoil in bringing new tools and talent on-line. Source selection should be considered whether such turmoil is under control—a mix of experience, employee satisfaction as evidenced by low turnover, functional integration (performance, quality, producibility, reliability, maintainability, cost input/output checks and balances), and an effective system security.

Design Reviews. The design reviews are the basic tools through which the manager controls the design. But, as is the case with most program review points, if a problem is identified first at the review, then communication has been lacking. Continuing communication about design status between buyer and seller is required largely because of the dynamic and complex nature of DOD systems and their relationship to the external acquisition environment; e.g., the Congress, administration and changing threats. However, the design-review process shown in Figure 55 offers a convenient framework to put product definition in perspective within the system engineering/technical management process. Appendix C discusses Figure 55 in depth and puts product definition in perspective as the common thread in technical management life-cycle activities.

Product Definition Action. The following are offered as considerations in managing design action:

* Tasks are phase dependent
* Avoid self-imposed constraints
* Establish a schedule
* Form a multidisciplined team
* Work hard on source selection
* Define production cost goal
* Establish warranty position
* Define O&S cost elements that are program cost goals
* Analyze incentives in depth
* Focus on cost early
* Identify cost elements to be considered
* Establish difficult, but achievable, goals
* Make provisions for change
* Provide flexibility
* Establish feedback mechanisms
* Do risk assessment
* Conduct in-process reviews.

We're asking the designer to sit at the center of generative design loops shown in Figure 4 and iterate and iterate until the optimum solution appears. It is a formidable task, which computers should make easier from the standpoint of providing needed data on a more real-time basis. It

is the manager's job to see that the required data is being supplied in a timely fashion and that the designer is using it. The ultimate check will occur when actual measures of a program are accumulated, but that will be far too late for effective management action.

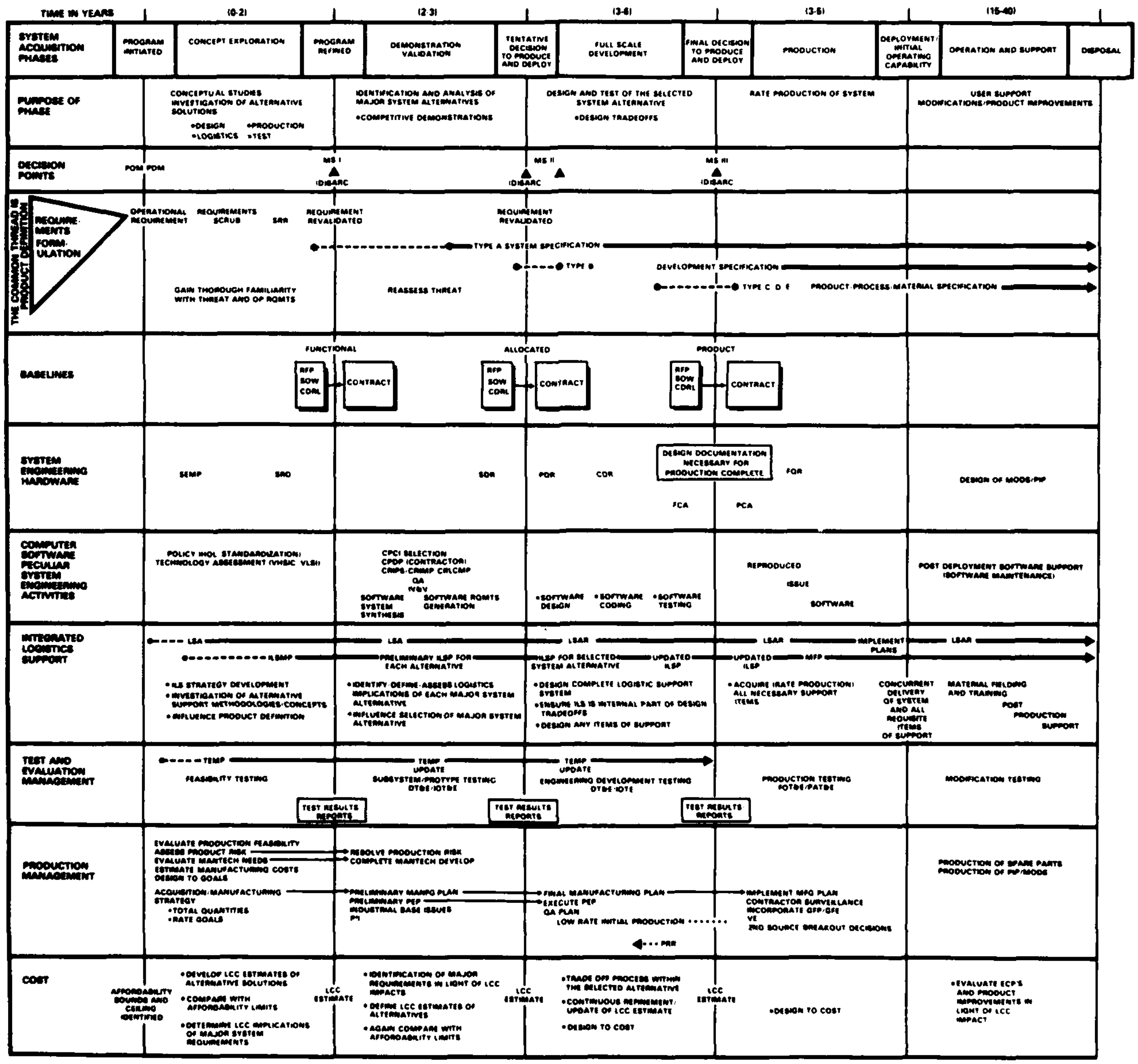
The State of the Art in DOD Product Design

Implementation of product design is undergoing rapid change. Drafting tools are changing from manual (remember T squares, pencils, and slide rules?) to computer aided (Figure 56). Data inputs are increasing in detail and speed. Complex relationships can be explored in great depth. There is a new generation of designers adept at using the new tools and integrating computer inputs. This new generation is an unfamiliar force in design/drafting—a force which must be reckned with in "people management" and technical management.

Design Tools

The interrelationships among conceptual design, preliminary design and production design of an air-

Figure 55. Acquisition Life-Cycle Technical Activities



craft are illustrated in Figure 57. The area through the middle is accomplished through first generation computer aided design (CAD). As CAD moves into the second and third generations, all the tasks are accomplished "real time" through CAD and associated analysis.

First generation CAD provides descriptive geometry on an interactive graphics terminal. This essentially allows the designer to shape/size/dimension a given part using the computer. The second generation of CAD adds three dimensional methodologies to provide improved visualization of the design. Third generation CAD brings three dimensional modeling together with analytical and simulation models to allow the designer to "stress and test" the design before finalization—even to the point of precluding the need for (some) hard mockups.

CAD investments in products that improve the implementation of the design concept, compared to manual methods, have shown impressive payoffs in productivity (Reference t). Among the reasons for this are: Complex construction drawings can be done faster with a computer, repetitive construction entities do not have to be redrawn (can be called instantaneously from storage), geometry construction drawings can be directed by the computer (do not have to be calculated), and a designer's use of a Cathode Ray Tube (CRT) in an interactive mode is more intense and sustainable than a designer working at a drawing board.

Even higher productivity can be achieved through use of larger data bases to support designs from commonly used information, creation of families of drawings from layouts, deriving assembly details from the same geometric data base, and avoiding

Figure 56. *Shown at the left is Computer-aided Design performed on an Advanced Roster Workstation (ARW) capable of three-dimensional formations with the touch of the key pad.*

design errors in motion clearances and tolerances through computer accuracy. In addition to improving the development of drawings, the automatic calculation and display capabilities of CAD are useful and effective as inputs for determining characteristics like section properties, weight, volume, and finite surface configurations. Using CAD graphics to assist engineering analysis reduces mistakes in the complex manipulation of geometric data.

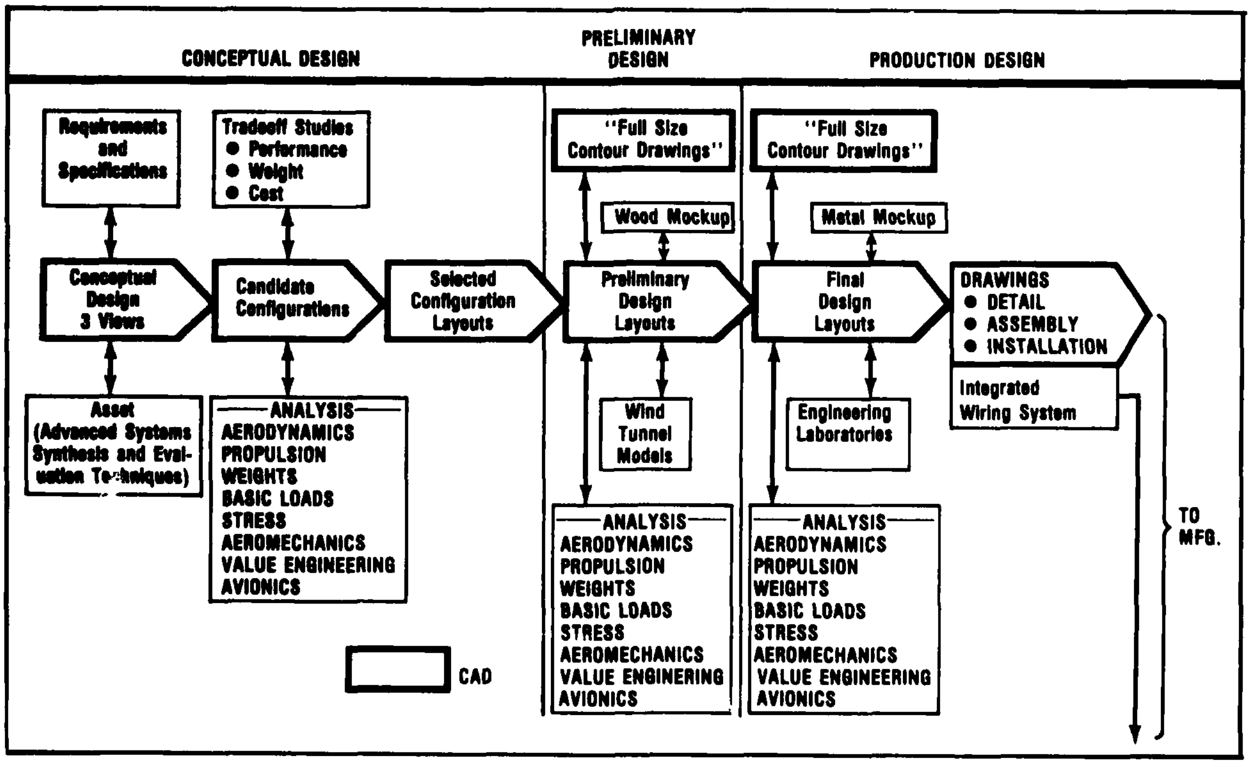
Thus, computers have a tremendous productive promise and they do very well the evolutionary task of product definition within given constraints (e.g., as long as the system architecture and data base are appropriately maintained). So the program writers are key. They lock in the design choices and, other than eternal vigilance, there is no way to test the output relative to current technology choices and system interfaces. People forget functional dependencies because of the magnitude of the data involved. This pitfall will get deeper with time as more and more interfaces and data inputs are related to the design data base. Ironically, this will put computers in the role of limiting advances unless the pitfall is addressed.

CAD Linkage to Computer-Aided Manufacturing (CAM)

Emphasis on productivity improvement is directed at the manufacturing process because the tasks are typically repetitive and labor intensive and because manufacturing costs of DOD defense systems are generally three times greater than the development costs. Therefore, manufacturing organizations in the aerospace industry are a forcing function for acquiring and implementing computer-aided systems. This leads to CAD/CAM being a driving initiative followed closely by group technology and flexible machining systems.

The term CAD/CAM has different meaning to different enterprises. Here it means *integrated* computer-aided design and manufacture in the broadest sense. Many users have settled for a "stand-alone" CAD or, worse, a small segment of CAD such as computer-aided graphics. Similarly, others have seen CAD as numerically controlled (N/C) tools or as manufacturing resource planning (MRP). Fortunately, this type of thinking is being extended to broader horizons. Managers are

Figure 57. Computer-Aided Design



looking to the payback from the synergism of an integrated design and manufacturing system such as that shown conceptually in Figure 58.

Real productivity improvement occurs when computerized systems are configured to use data bases shared by both engineering and manufacturing organizations. There are numerous CAM applications such as computer-aided process planning (CAPP) and computer-aided material planning and purchasing (CAMPP).

The data base management system is a major determinant in the success of a computer integrated manufacturing system. Data bases are powerful sets of software programs that control file structure with a practical balance of integrity, security, resource costs, and ease of understanding. Though only becoming a practical reality in the late 1970s, software programs, software files, and CAD/CAM inputs are no longer separable; they must function together in a smooth-running, integrated, total system. These three integrate all of the manufacturing related functions into one monolithic computer system (Computer Integrated Manufacturing). This goes well beyond traditional CAD/CAM concepts and extends the limits of computer systems.

CAD Linkage With Computer-Aided Test

Comprehensive test activity is fundamental to an effective design and manufacturing process. In the product cycle from the evaluation of initial design concepts to the physical verification of a manufactured part, some method of measurement is necessary. The evolution of computer technology in general and CAD/CAM in particular provide an enhanced capability to plan and conduct an integrated test program.

CAD enhances the early design phase by the use of test simulations. This capability is expanded during the system development phase through hardware in-the-loop simulation to verify earlier parametric analysis and correlation with other test data. In addition, engineering, acceptance, and qualification testing are greatly facilitated by computer automation. With the increasing complexi-

Figure 58. Integrated CAD/CAM System

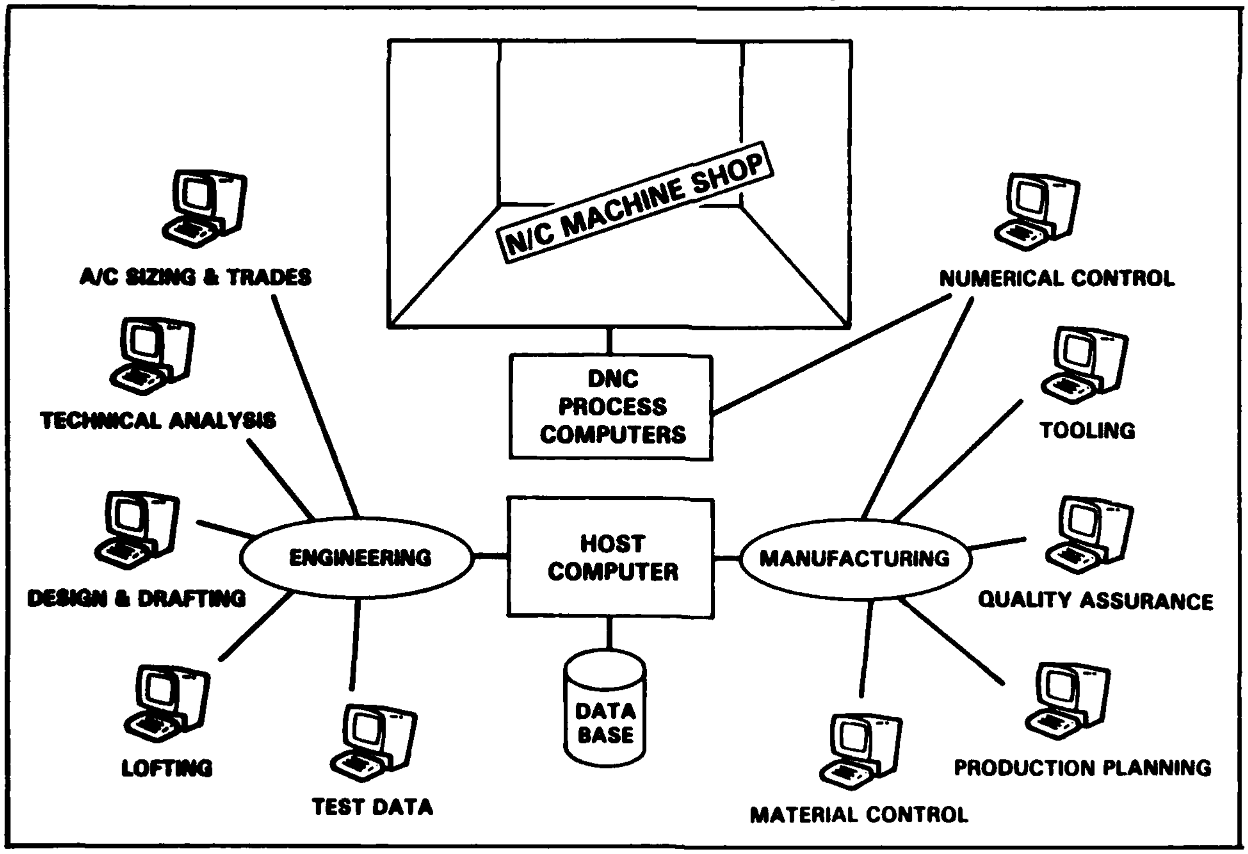
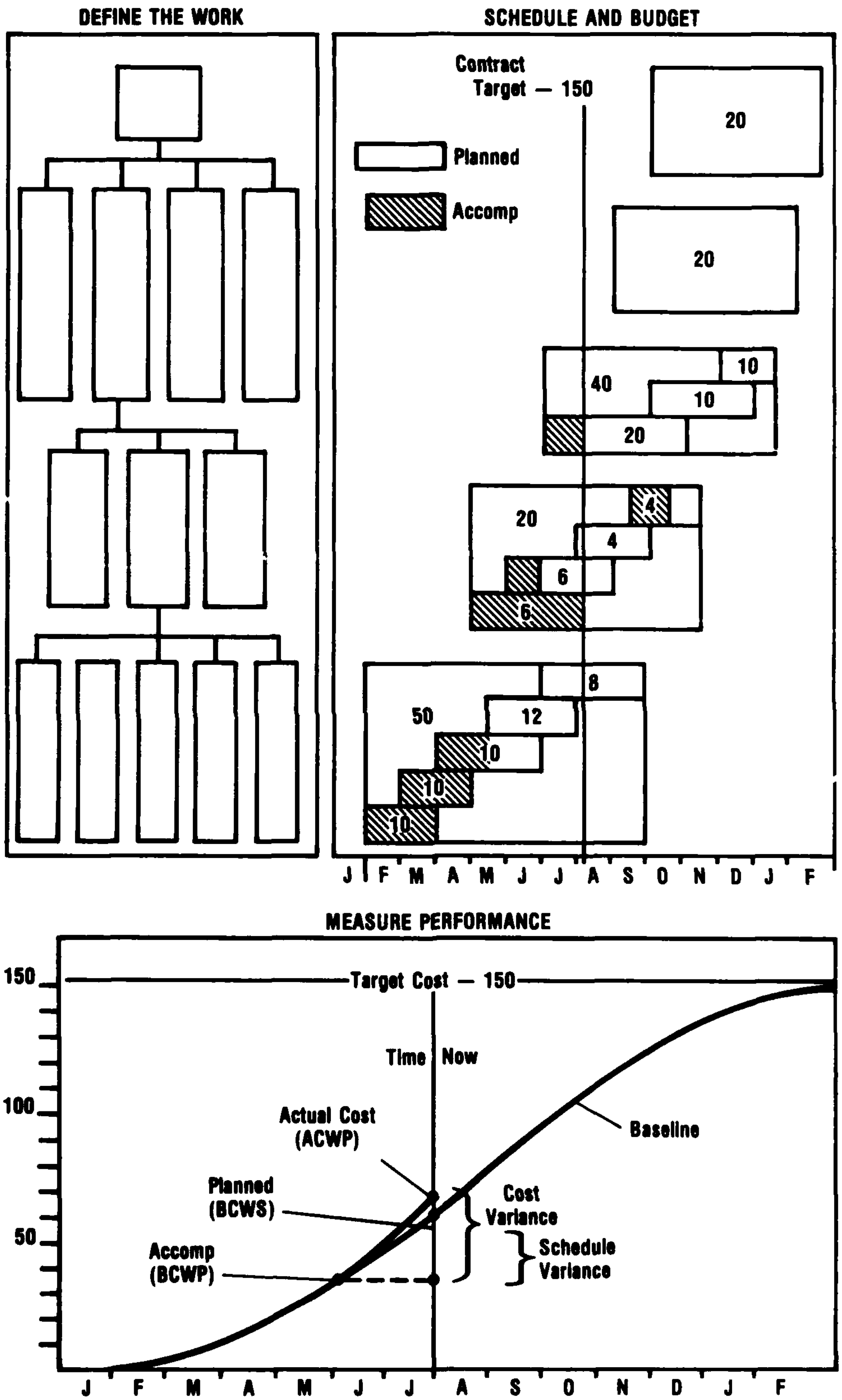


Figure 59. Summary—Basic C/SCSC Requirements



ty of equipments, especially electronics, it is nearly impossible to evaluate all test points in a timely fashion using manual methods. Computer-directed tests conduct these activities in minutes and provide hard copy printout without need for an individual to read meters and transcribe the data. Computer-aided technology assists in evaluating the interfaces between hardware and software with system "end-to-end" testing.

CAD Linkage With Computer-Aided Cost Analysis

For as long as computers have existed they have been used for cost accounting. Use was associated with various cost-estimating techniques and models or with the classic "after-the-fact" accounting. Computers were also applied to the automated formatting and manipulation of cost information to generate various reports, documents, charts, and tables. The capability expanded to document what is happening by tracking costs through systems like C/SCSC (cost/schedule control system criteria, Figure 59). Though the ability to *track cost* has improved to "near real time," cost prediction as a design tool lags.

The real payoff in computer-aided cost occurs when life-cycle cost and design to cost estimations are linked through real time algorithms to CAD. This enables cost to be accurately reflected as a design criteria with cost implications of a given design portrayed in "real time" to the designer.

CAD Linkage to Computer-Aided Logistics

Since operation and support of a defense system are such a large part of the life-cycle cost, the application of computers to this functional area can be very productive as it has been in CAD/CAM.

Figure 60. Design Workplace of the '50s

Like the manufacturing function, the power of the computer has been first applied to tedious or repetitive tasks.

In this case, applications were first found in Logistic Support Analysis (LSA), spares management, and documentation generation. The applications fell into two categories. These were modeling (like simulated logistic alterations, estimated life-cycle costs, predictability level of repair requirement) and accounting (like invoices, utilization trees, and checking status against plans). The CAD was applied as the product definition base for some computer-aided logistic tasks. This succeeded in creating "islands of automation" rather than an integrated net.

A Focus for Computer-Aided Technical Management

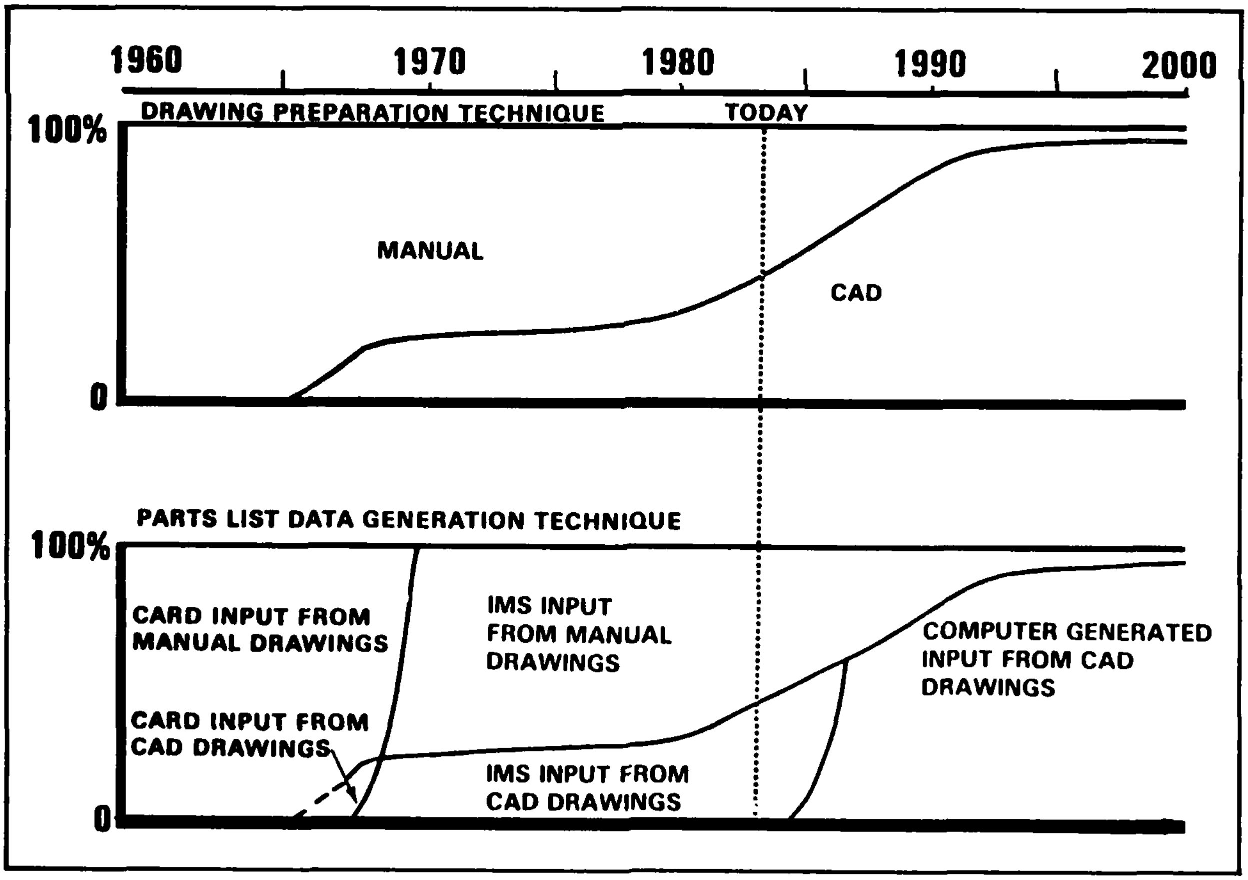
DOD has taken the lead in facilitating development of an integrated net for including logistic considerations (Reference u). Specific areas of concentration included data exchange standards, system demonstrations, and establishing architecture, resources and responsibilities for system development. This initiative will provide significant benefits:

* Early application in the development cycle which permits interaction and reaction to logistic support requirements thus creating more supportable systems
* Application of automation to logistic products thereby generating lower cost but greater accuracy
* Application of automated communication which generates less paper but provides quicker updates.

The New Generation of Designers

The implementation of computer aids in the functional areas and in the broader scheme of an integrated system requires users of the new CAD

Figure 61. Automating the Generation of the Product Definition Data Base



tools. There is an ever-increasing number of entry-level designers adept with those tools; but, interest in this new technology is not easily aroused in the experienced staff who grew up in a different work place (Figure 60).

Therefore, design activities are faced with a serious issue—go with the current age of designers who can use the tools but don't have the experience or teach the experienced designers how to use the tools. Either extreme or a mix implies turmoil in the design function and a real management opportunity. The issue has been addressed by some operations but, as Figure 61 shows, there is a long way to go.

Management could select either of the above described extremes, but the general approach is a mix (Reference v). The mixes have included CAD technology transfer to design experience and/or the reverse, and then elimination of non-productive participants. Various incentives have been used to stimulate the procedure including:

* The threat of elimination through the above process
* Pay supplements for experienced designers who demonstrate CAD proficiency before a certain agreed date
* Released time to attend CAD education courses (using company equipment or compatible equipment off site)
* Tuition support for relevant courses
* Combinations of the above.

Obviously, if the elimination of non-productive participants appears to threaten the work force generally, a new set of "people management" problems emerges.

Implementation of CAD will continue because productivity of the process has been accepted (Reference t). However, through the mid 1980s, the general economy had not experienced the desired productivity improvement, and in DOD there was not a reduction in development time which would be one indicator of improved productivity for DOD products. Therefore, contemporary research addressed the characteristics of the good designer (Reference u). When the tools were T-squares, pencils, paper, and slide rules and the designer followed the product into the shop to get it built, there developed a relationship and "feel" for the result. Did that mean anything? If so, how can we get it back? Or should we?

As a counterbalance to that concern, we know that the designer using CAD tools can spend more time at the station thinking about problems, evaluating more alternatives, and integrating more details; it is a matter of comfort and release from repetitive detail. Therefore, the initial impact of CAD may have been (be) improvement of the quality of designs with long-term rewards to be reaped in the life cycle of the product. Given release from the "garbage in, garbage out" syndrome and conscious addition of training programs to maintain product "feel," quality of the design process should improve. Those are big "givens" that require eternal vigilance.

Design Process Management Opportunities

Both government and industry program managers are faced with source selection for product designs and the architecture of product definition systems. The following expands some topics introduced earlier for consideration in the selection process.

The Design Tools

Computer technology will continue to offer productivity and design quality enhancements for the foreseeable future. It will continue to be important to determine if potential sources have optimized design tools for the project at hand. Return on investment will continue to drive this optimization process and, therefore, CAD applications will remain uneven particularly in the subcontractor and supplier base. This does not suggest that all DOD industry must have the same design tools but rather that the best source will have the right system for the specific task. Key considerations (beyond productivity in the hands of the designer) include:

* Compatibility with data input, output, and retrieval
* Capability to communicate with interfacing systems in a timely manner
* Growth potential to remain current with the dynamic state of the art.

The Data Inputs

Computers applied to separate technical functional areas can overload the integrator with data (designers can become lost in the interface matrix of the system because of the magnitude of the data to be integrated in a manner represented in Figure 62). This limits advances in effective designs and productive design processes. In other words, the architectural application of the computer has a great deal to do with productivity of the design process and quality of system design.

Therefore, DOD will apply ever-increasing pressure to develop computer aids that integrate in near real time consideration of all the special engineering requirements (commonly called "ilities") associated with the product life-cycle. The evolution of CAD/CAM (or more properly CAM/CAD) was hastened as industry recognized the valuable linkage and, for the most part, had the process under internal control. It is not so simple to conceive or portray incentives for industry to incorporate real time integration of the "ilities" which first requires DOD definition of the requirements.

Since the potential for savings through life-cycle design is so great, the management response should be:

* Provide "design to" life-cycle requirements
* Select sources that recognize the life-cycle design requirement and publicize benefits of life-cycle design
* As the concept matures, apply productive cost evaluation factors to recognize sources (for life-cycle design) that will produce more predictable (higher quality) designs.

The Designers

Turmoil in the design room is really only beginning. The issues of molding experience with new tools and integrating masses of functional input data are only the tip of the iceberg. As time passes, the "old" experience will pass and the work force will look more homogenous—and more powerful. Who will control the actions of this central design figure and how? Maybe more important, can the employment demands of this powerful figure be met? There are several management opportunities in DOD design source selection from a "people management" viewpoint:

* Evaluate (at least relative to other sources) how well new design process technology has been internalized. How are life-cycle inputs entered into the design activity? How is consideration of inputs assured?
* Determine if the design process is predictable from a people point-of-view. Is the process mature or well defined so that people will harmonize and exchange data as necessary? Verify that estimates of design performance are based on demonstrated results of an existing system or determine the validity of estimates based on an unproven process.
* Underlying both of the above analyses should be a review of specific personnel management techniques to determine if proper training and experience will support the design effort and whether employee attitude will support the productive requirements.

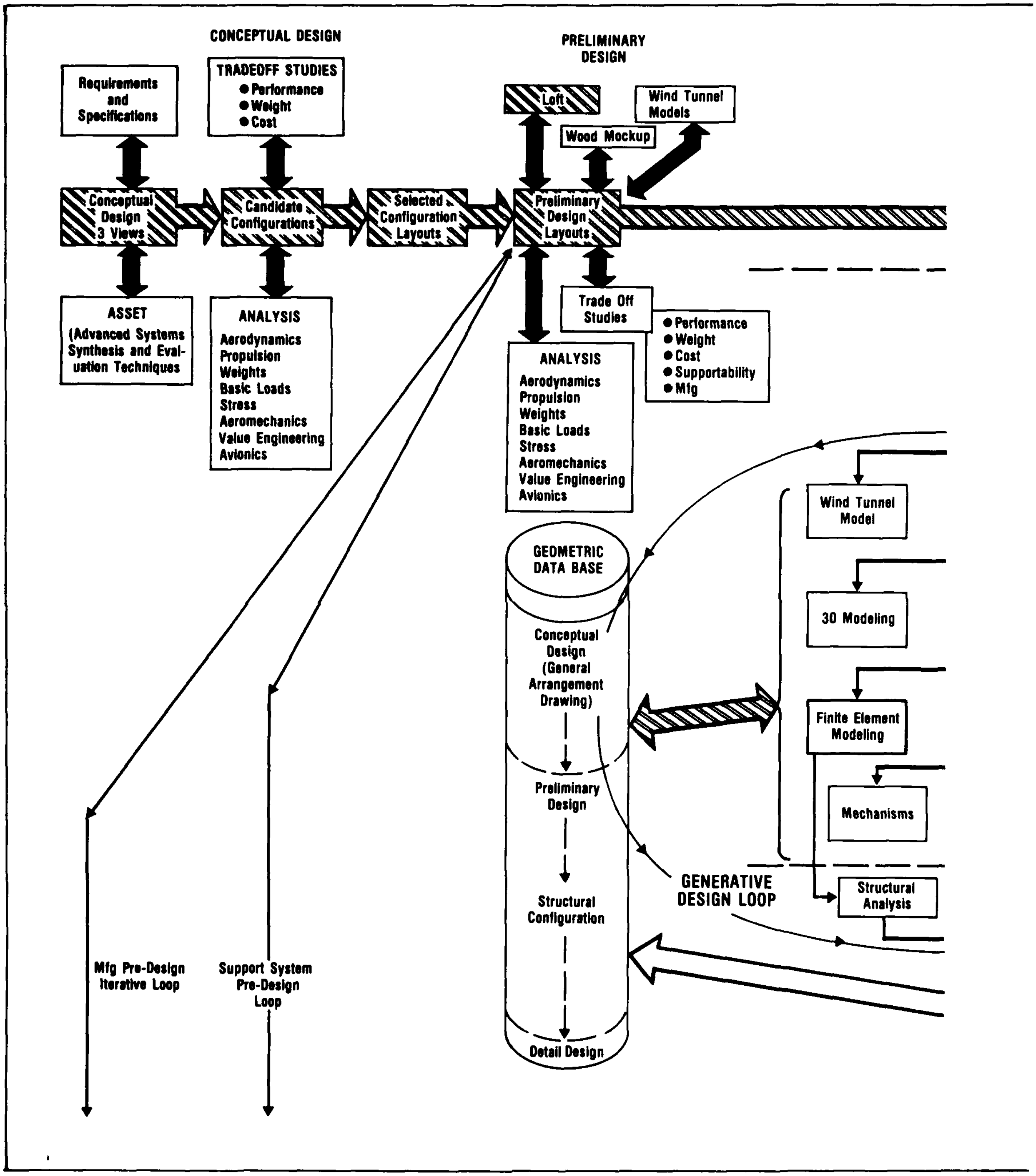
But, the most effective management action may be putting the "old" experienced designers to work with the programmers to ensure the capture of hard relationships, ensure flexibility in soft relationships, and provide eternal vigilance over the data base to protect creativity and innovation. Programs to test "ideas" are necessary to assure that new creations are possible (e.g., not locked out).

Product Definition Action

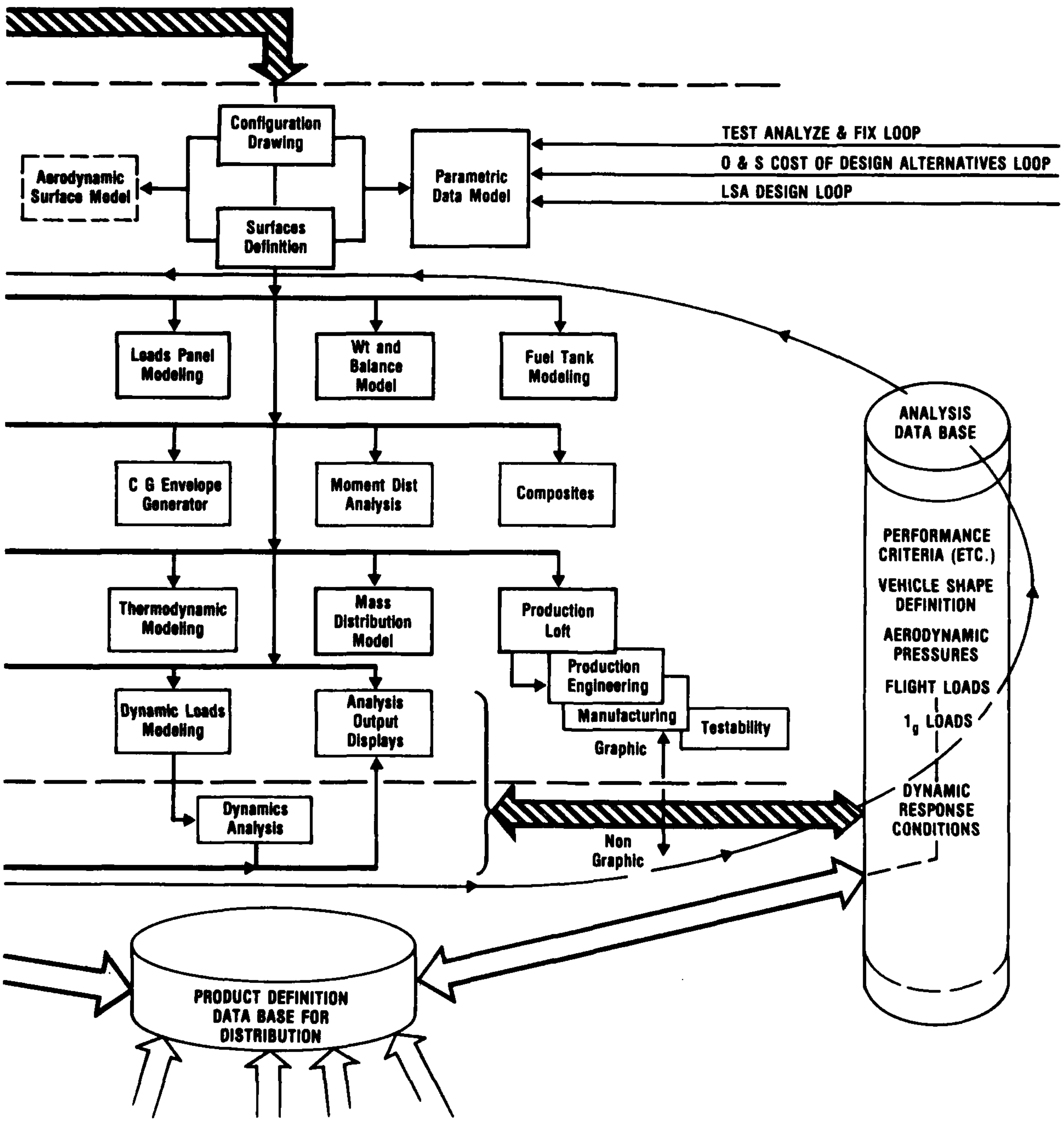
Obviously, the search is for a design source that has the tools and talent for the job at the right price. The buyer must evaluate the tools in terms of productive capacity to do the job, ability to generate alternatives and support tradeoffs, and compatibility of data output with system requirements. The designers must be adept at using the tools and experienced in the system design process. For the foreseeable future, design rooms will exhibit considerable turmoil in bringing new tools and talent on-line. Source selection should be based on assurance that such turmoil is under control.

The design review is the basic tool used by the DOD manager to control the design. However, as is the case with many program review points, if a problem is first identified at a design review then management communication has been lacking. The

Figure 62. Computer-Aided Product Definition



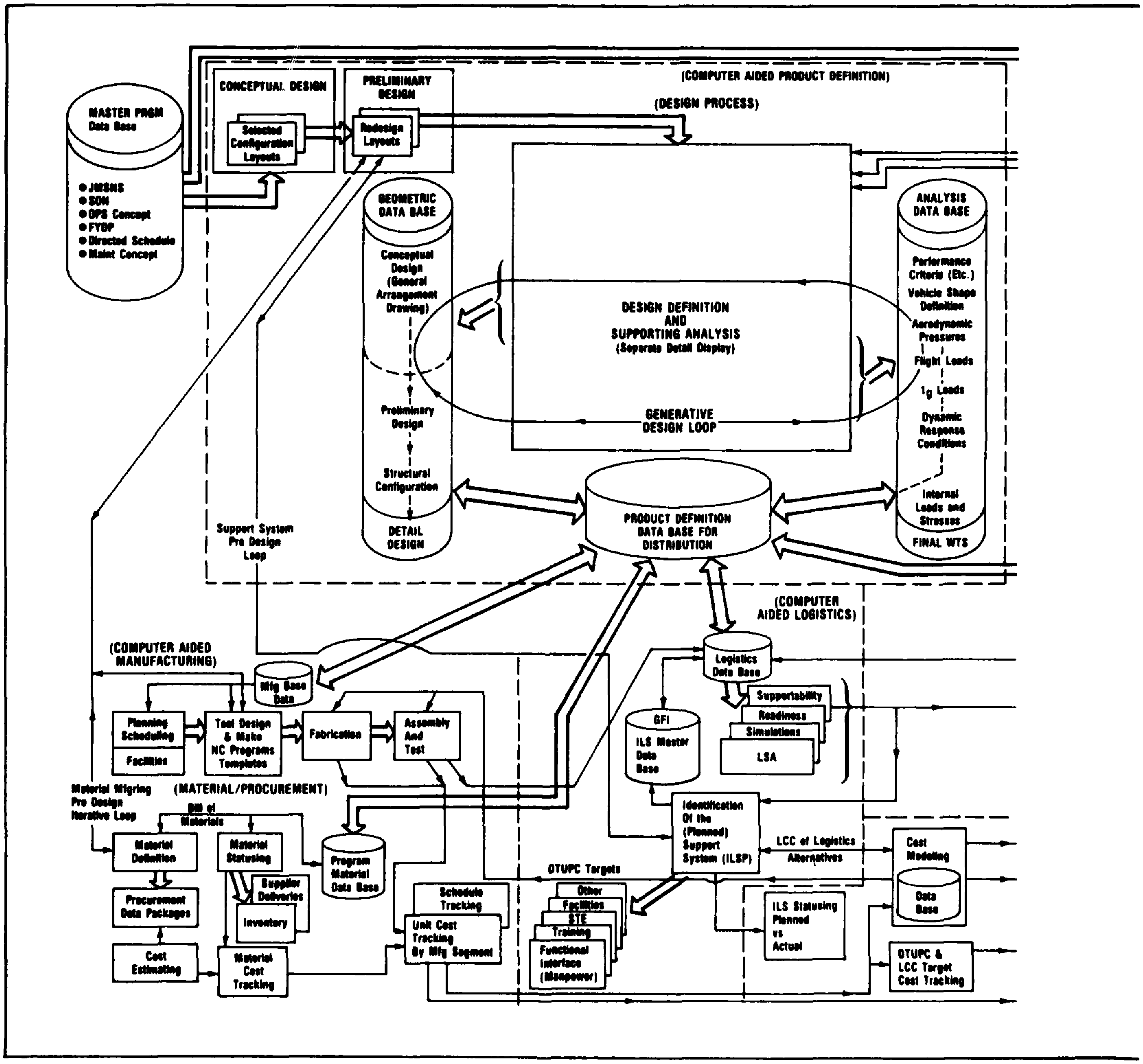
(DESIGN PROCESS)

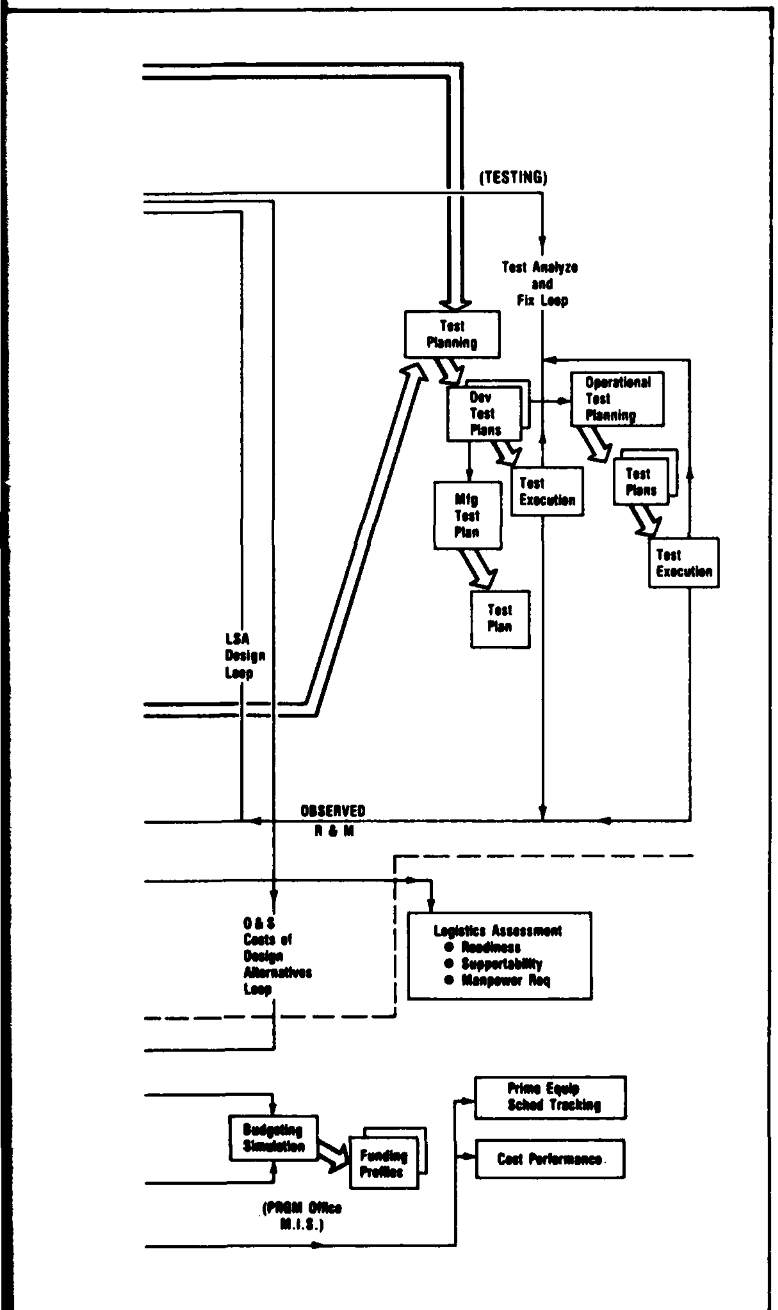


design review process offers a convenient framework to put product definition in perspective within the scope of system engineering/technical management (see Appendix C).

The designer sits at the center of a generative loop like that shown in Figures 62 and 63. The process is then one of iteration and integration until the optimum solution appears. Computer aids for this implementation represent a formidable task, but pieces are falling into place. It is the manager's job to guide the architectural growth of an effective product definition system. The process of using such a system is called computer-aided technical management (CATM).

Figure 63. Computer-Aided Technical Management




(TESTING)
Test Analyze and Fix Loop
Test Planning
Dev Test Plans
Operational Test Planning
Test Execution
Test Plans
Mfg Test Plan
Test Execution
Test Plan
LSA Design Loop
OBSERVED R & M
O & S Costs of Design Alternatives Loop
Logistics Assessment
Readiness
Supportability
Manpower Req
Prime Equip Sched Tracking
Budgeting Simulation
Funding Profiles
Cost Performance
(PRGM Office M.I.S.)

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APPENDIX A

Definitions of Important Terms
Designing for Reliability and Maintainability
(Reference g)

E/S = System effectiveness: The measure of the extent to which a system may be expected to achieve a set of specific mission requirements. It is a function of availability, dependability and capability.

A = Availability: A measure of the degree to which an item is in the operable and committable state at the start of a mission when the mission is called for at an unknown (random) time. (See Reliability, Availability and Maintainability).

D = Dependability: A measure of the degree to which an item is operable and capable of performing its required function at any (random) time during a specified mission profile, given item availability at the start of the mission.

C = Capability: A measure of the system ability to achieve the mission objectives, given the system condition during the mission.

RAM = Reliability, Availability and Maintainability: The RAM requirements are those imposed on acquisition systems to ensure they are operationally ready for use when needed, will successfully perform assigned functions and can be economically operated and maintained within the scope of logistics concepts and policies. RAM programs are applicable to materiel systems, test measurement and diagnostic equipment, training devices and facilities developed, produced, maintained, procured or modified for use (see individual definitions for Reliability, Availability, and Maintainability).

R = Reliability: A fundamental characteristic of an item of material expressed as the probability that it will perform its intended function for a specified period of time under stated conditions (see Reliability, Availability and Maintainability).

M = Maintainability: The ability of an item to be retained in or restored to specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair (see Reliability, Availability and Maintainability).

APPENDIX B
A Discussion of Availability Factors

To support the statement that over long operating periods, availability can be expressed (essentially) as a relationship between uptime (reliability) and downtime (maintainability), three types of availability (inherent availability: AI, achieved availability: AA, and operational availability: AO, will be discussed.

Inherent availability takes into account only items of system design. It is availability which assumes an ideal support environment and includes only active corrective maintenance time in calculation of downtime. It excludes preventive maintenance time and servicing time as well as supply, administrative and personnel delays. It is expressed in terms of its designed mean time between failures (MTBF) and its designed mean time to repair (or active repair time) (MTTR) given that it has failed:

AI = MTBF/(MTBF plus MTTR)

Achieved availability is calculated when preventive maintenance is included in the relationship. An ideal (no delay) support system is still assumed:

AA = MTBN/(MTBM plus MADT)

MTBM = mean time between maintenance both corrective and preventative

MADT = mean active downtime which includes the active elements of preventive and corrective maintenance

Operational availability includes all of the sources of non-operable time, active and inactive, including software downtime, supply and administrative delay times, corrective and preventive maintenance, personnel/maintenance technician delays (a function of items such as of manning policies, work cycles, training, health factors, personnel vulnerability in combat, location of duty areas and living quarters).

AO = MTBM/(MTBM plus MDT)

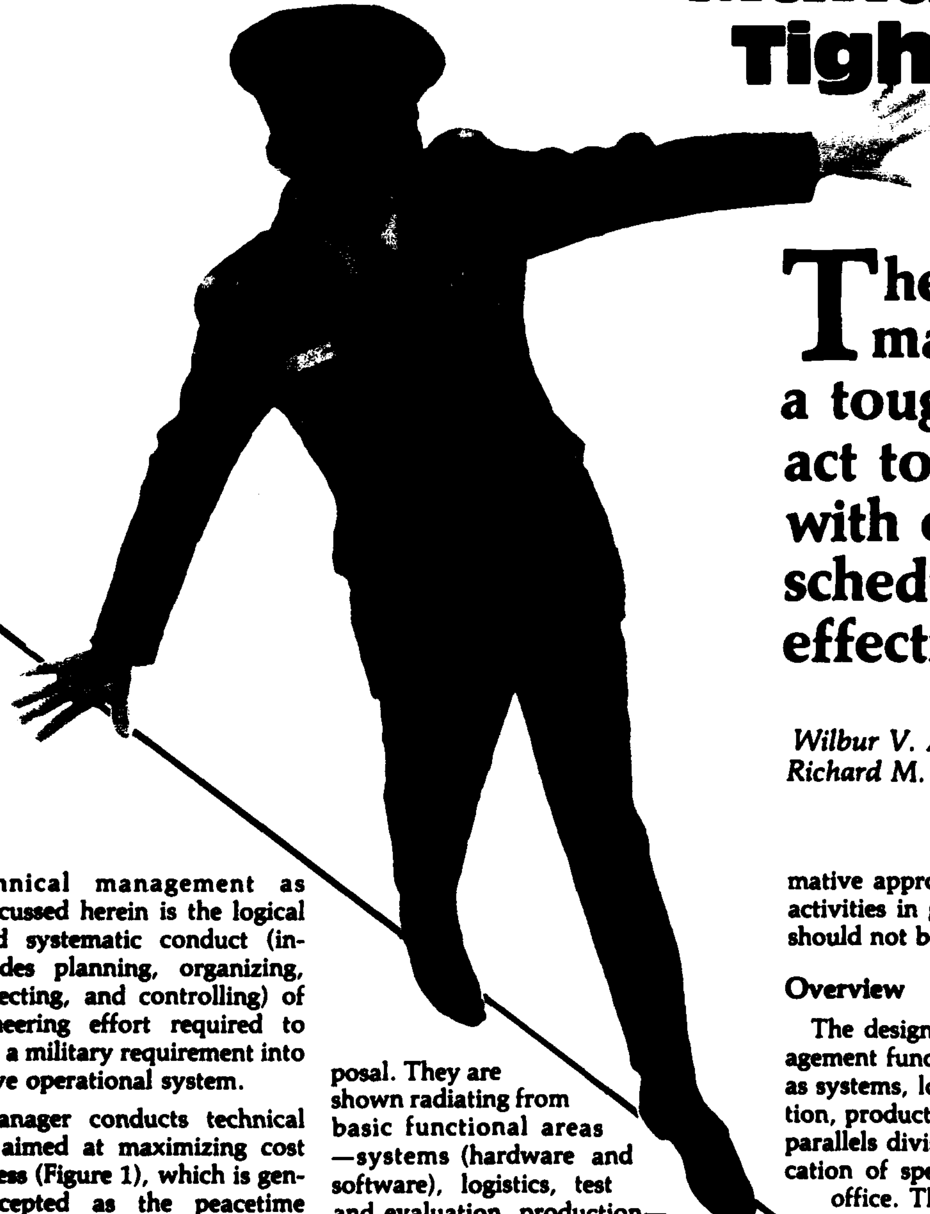
MDT = actual mean downtime and includes MADT plus administrative and logistic delay times

Note: To convert this relationship to cover total calendar time, add standby time (e.g., free time and storage time) to the numerator and denominator.

Estimating these availabilities, except in very simple cases, requires construction of a mathematical model which accounts for the interrelation of many factors across the system. The reader should appreciate that reliability is a major driver in the numerator of these relationships and an influence on the denominator as well. Maintainability is a major factor in MDT, MADT, and MTTR and, therefore, has significant influence in the denominator. This is the logic for the statement that the concept of availability is useful in trade-off studies for balancing reliability and maintainability requirements.

TECHNICAL MANAGEMENT

Balancing on the Technical Manager's Tightwire



The technical manager has a tough balance act to do—with cost, schedule, and effectiveness.

Wilbur V. Arnold
Richard M. Stepler

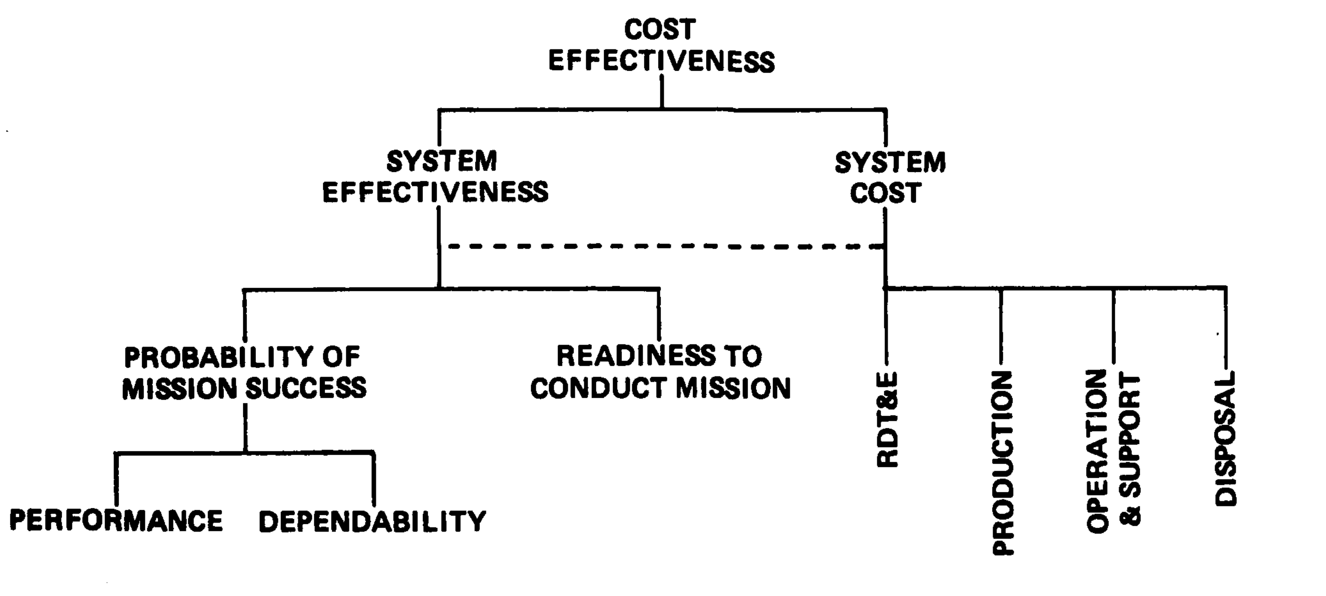
Technical management as discussed herein is the logical and systematic conduct (includes planning, organizing, directing, and controlling) of the engineering effort required to transform a military requirement into an effective operational system.

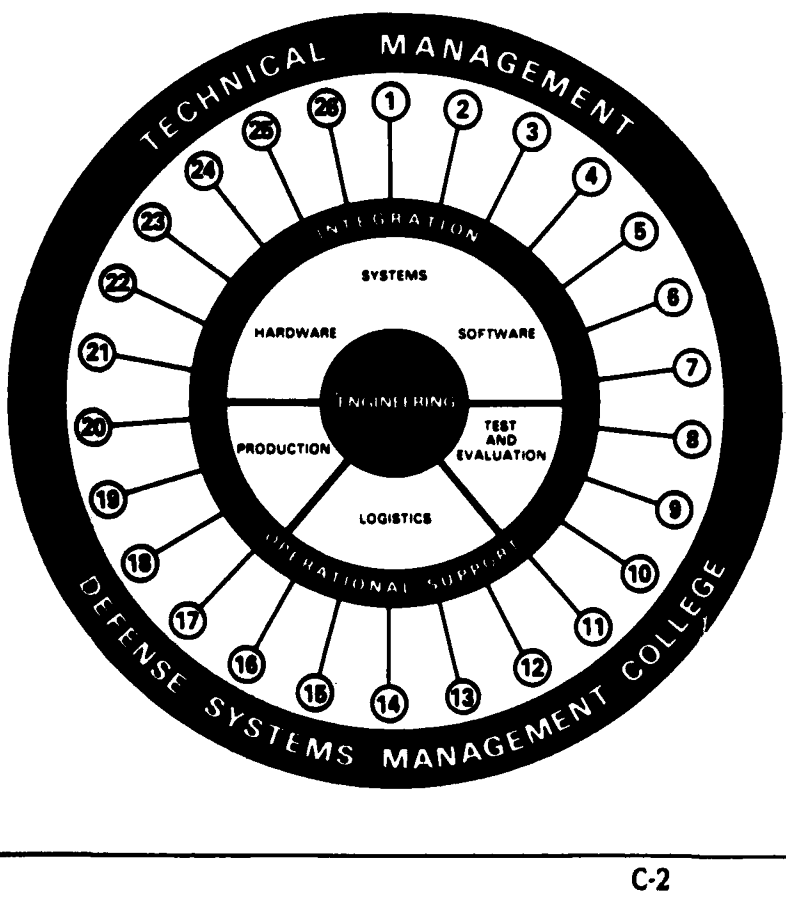
The manager conducts technical activities aimed at maximizing cost effectiveness (Figure 1), which is generally accepted as the peacetime measure of a program. This effort requires the technical manager to do a balancing act between cost, schedule, and effectiveness. What is the proper phasing of major activities in the balancing act which will result in a cost-effective program?

The most significant system acquisition elements are shown in Figure 2. The manager must integrate these into the technical effort of a system acquisition from initiation to disposal. They are shown radiating from basic functional areas—systems (hardware and software), logistics, test and evaluation, production—with engineering at the core. The figure illustrates the broad base and complexity of technical management. Operation within the specific disciplines is even more difficult. Therefore, the faculty of the Defense Systems Management College Technical Management Department developed the Acquisition Life Cycle Technical Activities Chart (see fold-out at the end of this article) as a management tool. The chart represents a normative approach to the broad-based activities in general time frames and should not be strictly interpreted.

Overview

The designation of technical management functional engineering areas as systems, logistics, test and evaluation, production, and cost sometimes parallels divisions of labor for application of specialties in the program office. There may be some argument that systems engineering encompasses all the technical functional areas and/or that logistics is a broader discipline than indicated. However, it is not our intention to create or address such controversy here, but merely to use the terms in formation of a matrix that exposes more detailed activities.





1. HARDWARE
2. ENVIRONMENTAL COMPATABILITY
3. HUMAN FACTORS
4. SURVIVABILITY VULNERABILITY
5. RELIABILITY MAINTAINABILITY AVAILABILITY
6. SAFETY
7. TESTABILITY
8. TEST SUPPORTABILITY
9. PACKAGING, HANDLING, TRANSPORTATION, STORAGE
10. SUPPLY SUPPORT/ PROVISIONING
11. SUPPORT AND TEST EQUIPMENT
12. DEPLOYABILITY
13. COMPUTER RESOURCE SUPPORT
14. MANUALS/ TECHNICAL DATA
15. FACILITIES
16. TRAINING
17. PERSONNEL
18. MAINTENANCE PLANNING
19. AFFORDABILITY
20. DESIGN TO COST
21. LIFE CYCLE COST
22. STANDARDIZATION COMMONALITY
23. PRODUCT ASSURANCE
24. PRODUCIBILITY
25. FIRMWARE
26. SOFTWARE

For our purposes, we use technical management as the broad discipline that encompasses all technical and functional areas.

The other variable of the matrix is program time. In this discussion, system acquisition phases—concept formulation, demonstration/validation, full-scale development, production and deployment—are convenient descriptors of time spans in which to group activities. In this way, technical management can be broken down to detailed activities by functional disciplines and program phase. The Acquisition Life-Cycle Technical Activities Chart provides a concise description of the activities.

There are important activities in all functional areas starting in the earliest phase of the acquisition life cycle and continuing through most of the program. The general thrust of technical management goes like this:

—*Define* what it takes to support, produce, and test the system utilizing analyses. Then see if we can afford it.
—*Influence the design* through producibility engineering, logistic analysis, testability design, and design to cost. Develop specifications and translate requirements to contract language.
—*Prepare to execute* by arranging for the test facilities, acquiring and setting up the production line, designing and acquiring the logistic support.
—*Execute* by testing, manufacturing, supporting.

The chart is a rigorous endeavor to show all the technical management activities in relative time phase. As such, it provides the manager a check list of activities that should be accomplished and integrated in the various program phases.

Delving into the details of the chart will soon confirm that hard work by management at the beginning will pay off later. Early technical decisions have a profound effect on total system cost and schedule, but there are continuing requirements for important technical activities and integration. The chart provides a guideline for accomplishing the technical management task. An explanation of functional discipline terminology is included at the end of this article.

Acquisition Life-Cycle Technical Activities

General

Technical activities are the genesis of a weapon system and continue through its life. The matrix in Figure 3 generally relates time to technical activities. The third dimension in managing this kind of effort is integration, that is, feedback and problem resolution between activities, and planning for the future. Any one management output must be based upon data and feedback developed during the generation of others. In other words, they must not only be consistent, but must also utilize the integrative power of functional consultation. The whole is greater than the sum of the parts.

There are some general integration flows that run through the chart:

—Specifications flow from systems (A) to development (B) to product (C), process (D), and material (E).
—These are reflected in the contract cycle: specification, statement of work (SOW), request for proposal (RFP) converted through the selection process to contractor effort.
—Product baseline is developed.
—The review process, i.e., system requirements review (SRR), system design review (SDR), preliminary design review (PDR), and critical design review (CDR), focuses integration/definition of the product.
—Test results provide feedback for analysis of performance progress.
—The overall technical management holds the activity together in the balancing act between cost, schedule, and effectiveness.

The following brief narrative addresses technical management activities and integration. We have tried to avoid getting lost depicting a maze of feedback loops, or attempting to articulate rigorous discussion of policy, rules, or differences between types of programs.

■*Mr. Arnold is a Professor of Engineering Management in the Technical Management Department, School of Systems Acquisition Education. Mr. Stepler was a Professor of Systems Acquisition Management in that department before recently transferring to Headquarters, Lexington Bluegrass Army Depot, in Kentucky.*

Concept Exploration

Document outputs of the concept exploration phase include:

—System specification (A)
 —Hardware
 —Software
—System requirement review (SRR)
 —Hardware
 —Software
—System engineering management plan (SEMP)
—Integrated logistics support master plan (ILSMP)
—Test and evaluation management plan (TEMP)
—Acquisition/manufacturing strategy
 —"Design to" goals
 —Total quantity
 —Production rate

The key effort during concept exploration is generation of the system (A) specification and establishment of the functional baseline. Supporting this activity and projecting the system engineering effort are the system requirements review and the system engineering master plan. These activities must require and consider realistic inputs from technical functions:

(1) The dynamic policy and technology of software;

(2) Logistics support implications (cost, schedule, performance) and requirements;

(3) Feasibility of testing and feasibility testing; and

(4) Producibility.

Demonstration/Validation (DEM/VAL)

Document outputs of the DEM/VAL phase include:

—Development specification (B)
 —Hardware
 —Software
—System design review (SDR)
 —Hardware
 —Software
—Integrated logistics support plan (ILSP)
—Logistic support analysis (see also concept exploration)
—Prototype test results
—Test and evaluation master plan update
—Resolution of production risk(s)
—Preliminary manufacturing plan

As the development specification is generated and the allocated baseline established, the functional specialists

continue to expand knowledge of the system, generate input for system design, and define the remaining program tasks.

Software. A system software synthesis is conducted and system requirements established. The basis for monitoring quality is established and the effort commences. An independent verification and validation approach is selected (or not) and the procedure starts.

Logistics. The logistics support system concept is developed. Logistics support analysis is conducted/continued to determine (current) alternatives and system design drivers.

Test and Evaluation. Prototype testing is conducted and reported. The test and evaluation master plan is updated for the current technology and system design. Better techniques may be available to accomplish T&E; the design may change and require a different T&E approach.

Production. Producibility paper studies are turned into technical modification/manufacturing technology programs, preliminary production engineering, and preliminary manufacturing plans. Preplanned product improvement feedback is provided.

Full-Scale Development (FSD)

Document outputs of the FSD phase include:

—Product specification (C)
  —Hardware
  —Software
—Process specification (D)
—Material specification (E)
—Logistics support definition
—Engineering development test report(s)
—T&E master plan update
—Manufacturing plan
—Production readiness review report
—Design documentation
  —Rate production
  —Complete support
—Quality assurance plan

As the final details of the system design are committed to specification:

—Software is designed, coded, tested, and product specification finalized;
—Logistics support is defined and acquisition started;
—Development test results are reported and the T&E master plan updated for current technology and design change;
—Development test and evaluation flows into initial operational test and evaluation; and
—Production engineering is a driver for the final manufacturing plan, but earlier work should make this an optimization activity—low-rate initial production may be included—the evaluation/quality assurance plans are finalized—all in support of a demonstration of readiness for production.

Production and Deployment

Document outputs during Production and Deployment include:

—Functional quality review report
—Production configuration audit report
—Logistic documentation deliverables
—T&E reports for final operational and product assurance testing
—Product disclosure package
—Contractor(s) surveillance reports
—Implementation of manufacturing strategy
  —GFP support
  —Value engineering
  —Second source
  —Breakout

Detailed reviews are conducted to be sure that the design disclosure package is suitable for its intended use—system production to meet user requirements. Logistic deliverables—manuals, spares, fielding support training, maintenance—are acquired. The manufacturing plan is executed, including appropriate value engineering and tactical activities such as establishing a second source(s), component breakout, and preplanned product improvement (P^3I). The total effort eventually becomes post-production support (hardware and software) wherein most if not all of the system effort is conducted within the using military service.

Summary

Criticism of weapon system acquisition costs has focused a great deal of attention on the procurement process. Initiatives to improve the process are being implemented. The chart is intended to advance the thought that the best way to improve the acquisition process is to do it the way it is supposed to be done. Most problems can be traced to ignoring essential activities (such as life-cycle analysis, logistic support analysis, producibility engineering) or taking "short cuts" that require extensive effort to "back fill" later. Timely technical activities should develop appropriate specifications, develop producible designs, provide meaningful evaluation, encourage productive facilities, provide effective support, budget and contract for effective production, and maintain system readiness.

This is the first publication of the chart. It is intended for use in program management offices and by others concerned with understanding the technical aspects of the system acquisition process. The content is oriented toward a large system procurement, but the flow of activity should be generally applicable to weapon systems. Comment is encouraged and should be directed to the authors at the publication address. Reproductions of the chart are available by writing Technical Management Chart, Defense Systems Management College, ATTN: SE-T, Fort Belvoir, Va. 22060.

FUNCTIONAL TERMINOLOGY AND USAGE

Production Definition

Requirements scrub. Review of user/government comments received in response to announcement of an operational requirement. The scrub is used to validate and prioritize suggested/requested system functions/capabilities before release to industry.

System requirements review (SRR). To ensure that system requirements have been completely and properly identified and that there is a mutual understanding between the government and contractor.

Type A, B, C, D, E specifications. See functional, allocated, and product baselines.

Baselines

Functional baseline. The technical portion of the program requirements (type A spec); provides the basis for contracting and controlling the system design.

Allocated baseline. Development specification (type B spec) defines the performance requirements for each

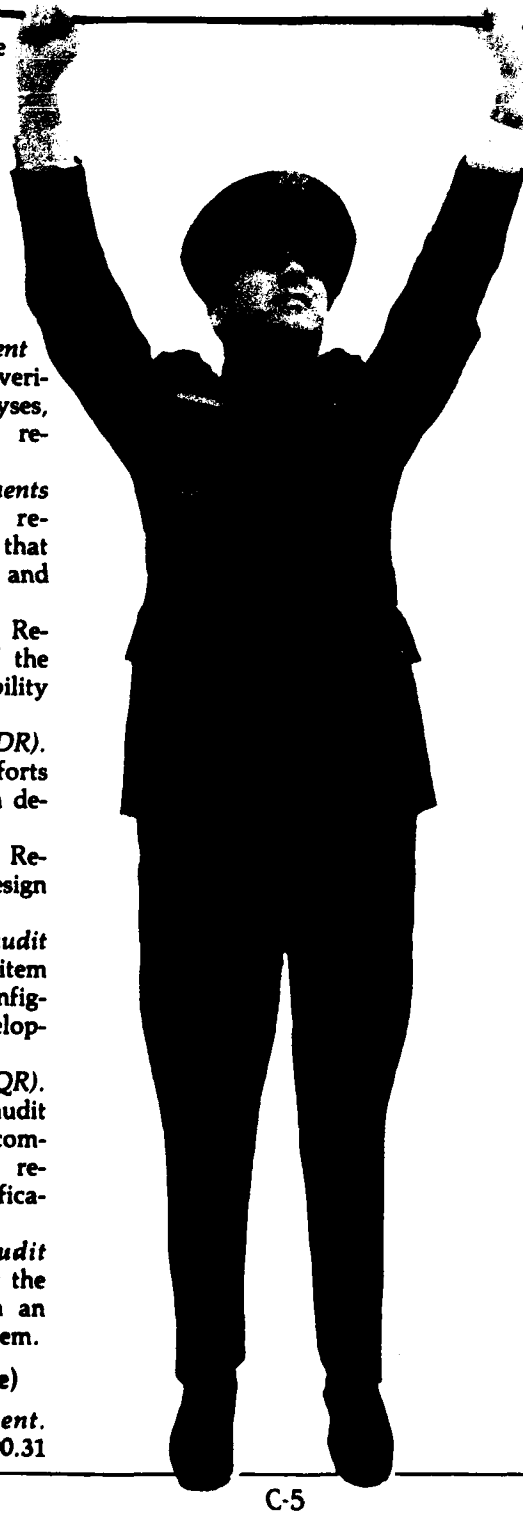
configuration item of the system.

Product baseline (type C spec). Established by the detail design documentation for each configuration item. Normally includes:

—*Process baseline* (type D spec); and

—*Material baseline* (type E spec).

Request for proposal (RFP), statement of work (SOW), contract data requirements list (CDRL). The documents used in letting contracts for each phase of work. The RFP sets forth the needs; the SOW is the formal statement of these needs as requirements for contractual effort; and the CDRL defines the data deliverables.



System Engineering (Hardware)

System engineering management plan (SEMP). Includes plans for verification, risk alleviation, analyses, and simulation of the system requirements.

System requirement documents (SRD). Refine the mission requirements through analysis that evolves a system design concept and interfaces.

System design review (SDR). Reviews the conceptual design of the system and establishes its capability to satisfy requirements.

Preliminary design review (PDR). Follows preliminary design efforts and results in approval to begin detailed design.

Critical design review (CDR). Reviews the completeness of the design and interfaces.

Functional configuration audit (FCA). Verifies that the actual item that represents the production configuration complies with the development specification.

Formal qualification review (FQR). A systems-level configuration audit conducted after system testing is completed (to ensure performance requirements of the system specification have been met).

Physical configuration audit (PCA). A means of establishing the product baseline as reflected in an early production configuration item.

Systems Engineering (Software)

Policy/technology assessment. DOD Directives 5000.29 and 5000.31 reflect current DOD policies. Additional information is in AR 1001-1 (Army), Mil-S-1679 (Navy), and AFR 800-14 Vols. I and II (USAF).

Computer program development plan (CPDP). A management plan usually generated by the developer that presents the software effort.

Computer resources integrated support plan (CRISP) (USAF), computer resources management plan (CRMP) (Army), computer resources life-cycle management plan (CRLCMP) (Navy). Life-cycle software management plans developed by program managers and their management team.

Independent verification and validation (IV&V). An independent review of the software product for functional effectiveness and technical sufficiency.

Quality assurance (QA). The process of assuring that a software product is produced that performs properly, has minimum support requirements, and facilitates maintenance as specified.

Software system synthesis. The analysis of user/buyer requirements to produce functional requirements for software at the A-specification level.

Software requirements generation. The decomposition of the A-specification requirements into functional requirements that are allocated to software.

Software design. The designing of the software systems to meet the functional requirements allocated in the B-specification.

Software programming. The coding of the software in accordance with the software design.

Software testing. The testing of the software to the functional requirements presented in the B-specification.

System engineering (hardware) activities for SRR, SDR, PDR, CDR, FCA/PCA, A Spec, B Spec, C Spec also apply to software.

Integrated Logistics Support (ILS)

ILS strategy development. Logistics acquisition strategy is developed setting forth objectives, resources, management assumptions, extent of competition, proposed contractual vehicles, program structure, but with emphasis on maintenance approach, operational support patterns, constraints, significant items, contractor role, GFE, including life-cycle support, transition, warranties, and post-production support.

ILS alternatives/trade-offs assessment. Largely a data-gathering and model exercise. Data comes from "lessons learned" files, comparative analysis, technological opportunities,

use studies, field visits, standardization requirements, functional and military requirements, constraints, maintenance, and operational approaches. Analyses and assessments are made on the cost and effectiveness of supporting the identified alternatives.

Integrated logistics support management plan (ILSMP). The early logistics plan dealing with organizational authorities and responsibilities and containing broad logistics strategy, goals/thresholds, and maintenance concepts.

Integrated logistics support plan (ILSP). The formal planning document for logistics support. It is kept current through the program life. It sets forth the plan for operational support, provides a detailed ILS program to fit with the overall program, provides decision-making bodies with necessary ILS information to make sound decisions in system development and production, and provides the basis for ILS procurement packages-specifications RFPs, SOWs, source-selection evaluation, terms and conditions, CDRLs.

Logistics support analysis (LSA). A formal tool under MIL-STD-1388 that helps identify and trade off qualitative and quantitative logistics support requirements. It is a logical, documented basis from which to influence design and force a degree of requirements integration. It also provides a yardstick from which to assess logistics objective achievement.

Logistics support analysis record (LSAR). The formal notation of design results in stylized format using forms for operations and maintenance requirements, RAM, task analyses, S and TE, facilities, skill evaluation, supply support, ATE and TPS, and transportability. LSAR is the basis for training, personnel, supply provisioning and allowances construction, S and TE acquisition, facilities construction and preparation, and for maintenance—preventive and corrective. Reference MIL-STD-1388.

Material Fielding and Training. The action of checking out equipment functions and operator and maintenance personnel training after production and before turnover to users.

Post production support (PPS). The planning for and provision of logistics support to the system after the end item production line has closed down (often a 10-20 year period). Requires tailored support activity usually documented in a PPS ILSP.

Test and Evaluation (T&E)

Three types of T&E—development test and evaluation (DT&E), operational test and evaluation (OT&E), and production acceptance test and evaluation (PAT&E) occur during the acquisition cycle. DT&E is conducted to assist the engineering design and development process and to verify attainment of technical performance specifications and objectives. OT&E is conducted to estimate a system's operational effectiveness and suitability, identify needed modifications, and provide information on tactics, doctrine, organization, and personnel requirements. PAT&E is conducted on production items to demonstrate that those items meet the requirements and specifications of the procuring contracts or agreements. OT&E is further subdivided into two phases—initial operational test and evaluation (IOT&E) and follow-on operational test and evaluation (FOT&E). IOT&E must be conducted *before the production decision* (Milestone III) to provide a credible estimate of operational effectiveness and suitability. Therefore, IOT&E must be conducted on a system as close to a production configuration as possible, in an operationally realistic environment, by typical user personnel. FOT&E is conducted on the deployed system to determine if operational effectiveness and suitability is, in fact, being attained.

Test and evaluation master plan (TEMP). The test and evaluation master plan is the top-level test management document. The TEMP is prepared at the PMO level and includes inputs from all participating agencies, with special emphasis on the test requirements of the independent operational test agency. There is a 30-page limit imposed by DODD 5000.3; however, the TEMP must include a system and mission description, T&E management and schedules, the status and plans for development, operational, and production acceptance testing, critical T&E issues, and test resource requirements. Prior to Milestone I, the TEMP is submitted to the Director of Defense Test and Evaluation (DDT&E) for review and approval. This approval establishes a "contract" between the service and OSD for testing throughout the life cycle of the system, since the TEMP covers all phases of testing. Subsequent to its initial issue, the TEMP is updated at each major milestone. In-process updates can also be accomplished at any time there is a significant change to the test program specified in the approved TEMP.

Test results/reports. The conduct of testing, and the associated collection, reduction, and analysis of test data, is a continuous process throughout the acquisition life cycle. The issuance of formal development and operational test reports is typically aligned with the major milestones to provide the essential risk reduction information and to support the program decisions. The issuance of independent OT&E reports by the independent operation test agency is considered critical to the support of the DSARC decision process.

Information from testing is forwarded to OSD and Congress by both informal and formal means (including the dissemination of the aforementioned test reports). Formal T&E briefings are made to DDT&E and others in the OSD staff approximately 3 weeks before each DSARC for the system. Information on test results is transmitted to Congress on a recurring basis as part of the selected acquisition reports (SARs) and congressional data sheets (CDS).

Production

Evaluate production feasibility. Assess the likelihood that a system design concept can be produced using existing manufacturing technology.

Assess production risks. Estimate probabilities of success or failure in manufacturing.

Identify manufacturing technology needs. Discriminate manufacturing capabilities vs. requirements to define new facilities and equipment needs.

Estimate manufacturing cost. Develop estimates of the resources required for various systems alternatives.

Design to goals. Requirement- or policy-driven constraints on design parameters for the system.

Acquisition/manufacturing strategy. The approach to obtaining the total quantity of a system at some rate for some cost.

Resolve production risk. Demonstrate required advances beyond the current capability.

Complete manufacturing technology development. Manufacturing technology is developed through a phased approach from definition to demonstration. This represents the final demonstration of the integrated manufacturing scheme.

Preliminary manufacturing plan. A method of employing the facilities, tooling, and personnel resources to produce the design.

Preliminary producibility, engineering and planning (PEP). Initial application of design and analysis techniques to reduce the potential manufacturing burden.

Industrial base issues. Critical resources, skills, and long-lead materials and processes required by the system design.

Finalize manufacturing plan. Refine and formalize initial manufacturing plan.

Execute PEP. Incorporate the producibility analysis into the mainstream design effort.

QA plan. Initiate a quality assurance plan to include quality of design and quality of conformance.

Low rate initial production (LRIP). Low rate of output used to prove manufacturing technology and facilities at the beginning of production.

Production readiness review (PRR). Formal examination of a program to determine if the design of the product and process are ready for the production phase.

Contractor surveillance. Execution of production contracts incorporating appropriate quality assurance documentation and observation. Surveillance may be conducted by on-site government representatives, authorized specialists, the program office, or a combination.

Post-production support (manufacturing). Arrange for purchase of spare parts or a portion of normal production runs.

Value engineering (VE). A program to allow for the sharing of cost savings derived from improvements in the manufacturing processes.

Second source. Execution of established acquisition strategy to establish two producers for the part or system.

Breakout. Execution of established acquisition strategy to convert some parts or systems from contractor-furnished to government-furnished.

GFP support. Execution of contracts and management of items provided as government-furnished property to the contractor.

Life-cycle cost (LCC). The net expenditure (usually an estimate) for acquiring and using an item. ■

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Comment Sheet
for
Designing Defense Systems

This monograph describes contemporary tools, talent, issues, and techniques applicable to designing defense products. The objectives are to provide insight for managers concerned with the design function and to provide designers with better understanding of the scope, tools, and issues involved.

If you have comments, please tear this sheet out, write the comments in the space provided below, fold, tape closed, and mail. This form is pre-addressed and needs no postage.

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